PB83-121731

Feasibility Study of Granular Activated Carbon Adsorption and On-Site Regeneration Volume 1: Detailed Report

Cincinnati Water Works, OH

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Oct 82

U.S. Department of Commerce
National Technical Information Service
NTIS

PB83-121731

EPA-600/2-82-087a
October 1982

FEASIBILITY STUDY OF GRANULAR ACTIVATED CARBON ADSORPTION AND ON-SITE REGENERATION

Volume 1. Detailed Report.

by

Richard Miller
David J. Hartman
Cincinnati Water Works
Cincinnati, Ohio 45232

Cooperative Agreement No. CR805443

Project Officers
Jack DeMarco and Ben W. Lykins, Jr.
Drinking Water Research Division
Municipal Enviromental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

REPRODUCED BY
NATIONAL TECHNICAL INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/2-82-087a

2.

3. RECIPIENT'S ACCESSION NO.
PB83 121731

4. TITLE AND SUBTITLE
Feasibility Study of Granular Activated Carbon and On-Site Regeneration
Volume 1. Detailed Report

5. REPORT DATE
October 1982

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Richard Miller, David J. Hartman

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Cincinnati Water Works
4747 Spring Grove
Cincinnati, Ohio 45232

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.
CR805443

12. SPONSORING AGENCY NAME AND ADDRESS
Municipal Environmental Research Laboratory - Cin., OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE
EPA/600/14

15. SUPPLEMENTARY NOTES
Project Officer: Ben W. Lykins, Jr. (513-684-7460)

16. ABSTRACT

Most research pertaining to water quality and treatment methods conducted in the United States in the last decade utilized pilot-scale components. This project employed full-sized filters, post-filtration contactors and carbon regeneration furnace at one site to study carbon's ability to remove organics from Ohio River Water.

Various GAC bed depths and types were studied in order to compare organic removal efficiencies, bed lives, general water quality characteristics, the need of a sand underlayer and operational problems. Pilot-scale GAC components were also used to determine the reliability of pilot columns as indicators of the performance of full-scale components. The relative performance of lignite and bituminous-based GAC was also studied in pilot columns.

In the most important phase of this project, the relative performance of GAC filters to post-filtration GAC contactors was studied along with the most advantageous empty bed contact time for the GAC contactors and the effectiveness of on-site GAC regeneration. Finally, a significant aspect of this project was the development of preliminary cost estimates for full-plant conversion to GAC.

Volume I is the detailed report. Volume II includes data graphs not included in Volume I and microfilm images of all raw data developed under the project.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT
Release to Public

19. SECURITY CLASS *(This Report)*
Unclassified

20. SECURITY CLASS *(This page)*
Unclassified

21. NO. OF PAGES
305

22. PRICE

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communication link between the researcher and the user community.

This report presents the results of a field-scale research effort to evaluate granular activated carbon (GAC) adsorption and on-site fluidized bed reactivation. GAC units consisting of converted sand filters and contactors were studied to determine their performance relative to virgin and reactivated granular carbon. Extensive organic analyses were performed along with general water treatment plant parameters. Cost of GAC treatment and reactivation were collected and preliminary cost estimates of full-scale plant conversion to GAC were developed.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory

ABSTRACT

This project determines whether the use of granular activated carbon (GAC) is feasible for removing certain trace organics from Ohio River water while treating it for human consumption. The study used either deep-bed contactors or conventional-depth gravity filters and on-site GAC regeneration. To be considered feasible, the facility had to be able to remove selected organics to a predesignated level at a cost acceptable to consumers without adversely affecting the level of treatment provided by the existing plant. A secondary objective was to develop plant design and operating parameters for full-scale plant conversion to GAC treatment. The study was unusual in that it employed full-sized filters, contactors, and carbon regeneration furnace instead of the pilot-scale components used by most water quality researchers.

In the first phase of the project, three existing rapid sand filters were converted to GAC filter adsorbers. Various GAC bed depths and types were studied to compare organic removal efficiencies, bed lives, general water quality characteristics, the need of a sand underlayer and operational problems.

The second phase involved the use of pilot-scale GAC components to investigate the effects of regeneration on the carbon's adsorptive capability and to determine the reliability of polot column as performance indicators for full-scale components. The relative performances of lignite and bituminous-based GAC were also studied.

The last phase of this project studied the relative performance of GAC filters to post-filtration GAC contactors, the most advantageous empty bed contact time for the contactors and the effectiveness of on-site GAC regeneration. Pilot columns were also operated in parallel with the full-sized units to assess the usefulness of pilot columns as predictors of full-scale operation. During this phase, an attempt was made to maximize the use of currently available organic analysis techniques. Additional organic analytical techniques such as acid extract GC/FID profiles, Grob closed loop stripping analyses and carbon-adsorbable organohalides provided a broad data base. Finally, a significant aspect of this project was the development of preliminary cost estimates for full-plant conversion to GAC.

This report was submitted in fulfillment of Cooperative Agreement No. CR805443 by the Cincinnati Water Works under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from August, 1977 to May, 1982, and work was completed as of April, 1982.

CONTENTS

Disclaimer. ii
Foreword. iii
Abstract. iv
Figures vi
Tables. xiv
Abbreviations and Symbols xviii
Acknowledgments xxi

1. Introduction 1
2. Conclusions. 4
3. Recommendations. 6
4. Description of the Treatment Complex 7
    Filters 9
    Pilot columns 15
    Contactors. 21
    Regenerator 30
    Contactor/regenerator building. 35
    Laboratory. 35
    Data management 37
5. Methods and Operating Procedures 40
    Physical plant. 40
    Laboratory. 51
6. Results and Discussion 80
    Phase 1. Full-scale GAC Filters. 80
        Objective 1: Relative performance of GAC filters. . . 80
        Objective 2: Sand vs. GAC for filter media. 90
    Phase 2. Pilot GAC Filters and Contactors. 94
        Objective 3: Virgin vs. regenerated GAC 94
        Objective 4: Bituminous vs. lignite-based GAC 94
        Objective 5: Prediction of full-scale performance . . 107
    Phase 3. Full-scale GAC Filters and Contactors With On-site Regeneration 121
        Objective 6: Full-scale GAC filters vs. contactors. . 121
        Objective 7: Effect of regeneration 158
        Objective 8: Pilot vs. full-scale systems 173
        Objective 9: GAC exhaustion criteria. 193
        Objective 10: Regenerated GAC characteristics. 215
        Objective 11: GAC regeneration and transport losses. . 215
        Objective 12: Design parameters. 220
        Objective 13: Costs. 239
    Other Observations. 254

References. 265

Appendix

A. Computerized Data Dictionary 267

FIGURES

Number		Page
1	Treatment process	8
2	Filter and pipe gallery cross-section	11
3	Filter gallery layout	12
4	Filter carbon transport piping.	13
5	Pilot GAC filters, processing flow.	16
6	Pilot GAC filter, backwashing flow.	17
7	Lignite pilot contactor, processing flow.	19
8	Lignite pilot contactor, backwashing flow	20
9	Bituminous pilot contactor, processing flow	22
10	Bituminous pilot contactor, backwashing flow.	23
11	Contactor Building layout	24
12	Contactor cross-section	25
13	Regenerator process	31
14	Treatment process sample point locations.	52
15	Full-scale GAC system sample point locations	53
16	Maximum THM (MTTT) breakthrough curves for GAC Filters 21A level 2 and 19A effluent, Phase 1-0.	81
17	Total organic carbon (TOC) breakthrough curves for GAC Filter 19A and 21A effluents, Phase 1-0.	83
18	Maximum THM (MTTT) breakthrough curves for GAC Filter 19A and 21A effluents, Phase 1-0	84
19	Instantaneous THM (ITTT) concentration curves for GAC Filter 19A and 21A effluents, Phase 1-0.	85

20 Total organic carbon (TOC) breakthrough curves for GAC Filter 21A and 23A effluents, Phase 1-0. 88

21 Maximum THM (MTTT) breakthrough curves for GAC Filter 21A and 23A effluents, Phase 1-0 89

22 Instantaneous THM (ITTT) concentration curves for GAC Filter 21A and 23A effluents, Phase 1-0. 91

23 Total organic carbon (TOC) percent removal curves for virgin and once regenerated pilot GAC filter effluents, Phase 2-1 . 95

24 Instantaneous THM (ITTT) percent removal curves for virgin and once regenerated pilot GAC filter effluents, Phase 2-1 . . . 96

25 Seven-day simulated distribution syst. THM (STT7) percent removal curves for virgin and once regenerated pilot GAC filter effluents, Phase 2-1. 97

26 THM formation potential (FTTT) percent removal curves for virgin and once regenerated pilot GAC filter effluents, Phase 2-1. 98

27 Total organic carbon (TOC) percent removal curves for virgin and twice regenerated pilot GAC filter effluents, Phase 2-2. 99

28 Instantaneous THM (ITTT) percent removal curves for virgin and twice regenerated pilot GAC filter effluents, Phase 2-2. . . 100

29 Seven-day simulated distribution syst. THM (STT7) percent removal curves for virgin and twice regenerated pilot GAC filter effluents, Phase 2-2. 101

30 THM formation potential (FTTT) percent removal curves for virgin and twice regenerated pilot GAC filter effluents, Phase 2-2. 102

31 Total organic carbon (TOC) breakthrough curves for bituminous and lignite pilot contactor effluents, Phase 2-0 105

32 Seven-day simulated distribution system THM (STT7) breakthrough curves for bituminous and lignite pilot contactor effluents, Phase 2-0 106

33 Total organic carbon (TOC) breakthrough curve for virgin pilot GAC filter, Phase 2-1. 108

34 Instantaneous THM (ITTT) breakthrough curve for virgin pilot GAC filter, Phase 2-1. 109

35 Seven-day simulated distribution system THM (STT7) breakthrough curve for virgin pilot GAC filter, Phase 2-1. . 110

36 THM formation potential (FTTT) breakthrough curve for virgin pilot GAC filter, Phase 2-1 111

37 Total organic carbon (TOC) breakthrough curve for virgin pilot GAC filter, Phase 2-2. 112

38 Instantaneous THM (ITTT) breakthrough curve for virgin pilot GAC filter, Phase 2-2. 113

39 Seven-day simulated distribution system THM (STT7) breakthrough curve for virgin pilot GAC filter, Phase 2-2. . 114

40 THM formation potential (FTTT) breakthrough curve for virgin pilot GAC filter, Phase 2-2. 115

41 Total organic carbon (TOC) breakthrough curve for bituminous pilot contactor, Phase 2-0. 117

42 Instantaneous THM (ITTT) breakthrough curve for bituminous pilot contactor, Phase 2-0. 118

43 Seven-day simulated distribution system THM (STT7) breakthrough curve for bituminous pilot contactor, Phase 2-0. 119

44 THM formation potential (FTTT) breakthrough curve for bituminous pilot contactor, Phase 2-0. 120

45 Total organic carbon (TOC) breakthrough curves for GAC Filter 15A effluent and Contactor D level 7, Phase 3-0 . . . 122

46 Three-day simulated distribution system THM (STT3) breakthrough curves for GAC Filter 15A effluent and Contactor D level 7, Phase 3-0. 123

47 Instantaneous THM (ITTT) breakthrough curves for GAC Filter 15A effluent and Contactor D level 7, Phase 3-0. 124

48 THM formation potential (FTTT) breakthrough curves for GAC Filter 15A effluent and Contactor D level 7, Phase 3-0 . 125

49 Instantaneous THM (ITTT) breakthrough curves for GAC Filter 15A effluent and Contactor C level 7, Phase 3-1. 126

50 Instantaneous THM (ITTT) percent removal curves for GAC Filter 15A effluent and Contactor C level 7, Phase 3-1 . . . 128

51 THM formation potential (FTTT) percent removal curves for GAC Filter 15A effluent and Contactor D level 7, Phase 3-0 . . . 129

52 Carbon adsorbable organohalides (CAOX) breakthrough curves for GAC Filter 15A effluent and Contactor D level 7, Phase 3-0 . 130

53 Acid extract profiles for filter influent, GAC Filter 15A effluent and Contactor D level 7, Phase 3-0, runday eight. . 136

54 Acid extract profiles for filter influent, GAC Filter 15A effluent and Contactor D level 7, Phase 3-0, runday 85 . . . 137

55 Acid extract profiles for filter influent, GAC Filter 15A effluent and Contactor D level 7, Phase 3-0, runday 113. . . 138

56 Acid extract profiles for filter influent, GAC Filter 15A effluent and Contactor D level 7, Phase 3-0, runday 141. . . 139

57 Instantaneous chloroform (ICLR) breakthrough curves for Contactor D, Phase 3-0 145

58 Instantaneous bromodichloromethane (ICL2) breakthrough curves for Contactor D, Phase 3-0 146

59 Total organic carbon (TOC) breakthrough curves for Contactor D, Phase 3-0. 147

60 THM formation potential (FTTT) breakthrough curves for Contactor D, Phase 3-0 148

61 Three-day simulated distribution system THM (STT3) breakthrough curves for Contactor D, Phase 3-0 149

62 Carbon adsorbable organohalides (CAOX) breakthrough curves for Contactor D, Phase 3-0 150

63 Instantaneous chloroform (ICLR) carbon use rates for multiple runs of contactors, Phase 3 151

64 Instantaneous bromodichloromethane (ICL2) carbon use rates for multiple runs of contactors, Phase 3 153

65 Total organic carbon (TOC) carbon use rates for multiple runs of contactors, Phase 3. 154

66 Acid extract profiles for Contactor D, Phase 3-0, runday 29 . . 155

67 Acid extract profiles for Contactor D, Phase 3-0, runday 113. . 156

68 Total organic carbon (TOC) percent removal curves for multiple runs of Contactor D effluent, Phase 3 162

69 Three-day simulated distribution system THM (STT3) percent removal curves for multiple runs of Contactor D effluent, Phase 3. 163

70 Total organic carbon (TOC) percent removal curves for multiple runs of GAC Filter 15A effluent, Phase 3. 164

71 Instantaneous chloroform (ICLR) percent removal curves for multiple runs of GAC Filter 15A effluent, Phase 3. 165

72 Instantaneous chloroform (ICLR) adsorbed per GAC weight for multiple runs of Contactor D effluent, Phase 3 167

73 Instantaneous bromodichloromethane (ICL2) adsorbed per GAC weight for multiple runs of Contactor D effluent, Phase 3. . 168

74 Total organic carbon (TOC) adsorbed per GAC weight for multiple runs of Contactor D effluent, Phase 3 169

75 Instantaneous chloroform (ICLR) adsorbed per GAC weight for multiple runs of GAC Filter 15A effluent, Phase 3. 170

76 Total organic carbon (TOC) adsorbed per GAC weight for multiple runs of GAC Filter 15A effluent, Phase 3. 171

77 THM formation potential (FTTT) adsorbed per GAC weight for multiple runs of GAC Filter 15A effluent, Phase 3. 172

78 Three-day simulated distribution system THM (STT3) percent removal curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-0 174

79 Total orgznic carbon (TOC) percent removal curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-0 175

80 Three-day simulated distribution system THM (STT3) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-0. 177

81 Total organic carbon (TOC) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-0 178

82 Three-day simulated distribution system THM (STT3) percent removal curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-1 179

83 Total organic carbon (TOC) percent removal curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-1 180

84 Three-day simulated distribution system THM (STT3) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-1. 181

85 Total organic carbon (TOC) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-1 182

86 Three-day simulated distribution system THM (STT3) percent removal curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-2 183

87 Total organic carbon (TOC) percent removal curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-2 184

88 Three-day simulated distribution system THM (STT3) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-2. 185

89 Total organic carbon TOC breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-2 186

90 Three-day simulated distribution system THM (STT3) percent removal curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-3 187

91 Total organic carbon (TOC) percent removal curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-3 188

92 Three-day simulated distribution system THM (STT3) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-3. 189

93 Total organic carbon (TOC) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-3 190

94 Acid extract profiles for GAC Filter 15A and pilot GAC filter, Phase 3-0, runday 57 191

95 Carbon adsorbable organohalides (CAOX) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-0 . . 192

96 Three-day simulated distribution syst. THM (STT3) percent removal curves for bituminous pilot contactor and Contactor D effluents, Phase 3-0 194

97 Total organic carbon (TOC) percent removal curves for bituminous pilot contactor and Contactor D effluents, Phase 3-0. 195

98 Three-day simulated distribution system THM (STT3) breakthough curves for bituminous pilot contactor and Contactor D effluents, Phase 3-0 196

99 Total organic carbon (TOC) breakthrough curves for bituminous pilot contactor and Contactor D effluents, Phase 3-0 197

100 Three-day simulated distribution syst. THM (STT3) percent removal curves for bituminous pilot contactor and Contactor D effluents, Phase 3-1 198

101 Total organic carbon (TOC) percent removal curves for bituminous pilot contactor and Contactor D effluents, Phase 3-1. 199

102 Three-day simulated distribution system THM (STT3) breakthrough curves for bituminous pilot contactor and Contactor D effluents, Phase 3-1 200

103 Total organic carbon (TOC) breakthrough curves for bituminous pilot contactor and Contactor D effluents, Phase 3-1 201

104 Three-day simulated distribution syst. THM (STT3) percent removal curves for bituminous pilot contactor & Contactor D effluents, Phase 3-2 202

105 Total organic carbon (TOC) percent removal curves for bituminous pilot contactor and Contactor D effluents, Phase 3-2. 203

106 Three-day simulated distribution system THM (STT3) breakthrough curves for bituminous pilot contactor and Contactor D effluents, Phase 3-2 204

107 Total organic carbon (TOC) breakthrough curves for bituminous pilot contactor and Contactor D effluents, Phase 3-2 205

108 Acid extract profiles for Contactor D and pilot contactor, Phase 3-0, runday 113. 206

109 Carbon adsorbable organohalides (CAOX) breakthrough curves for pilot contactor and Contactor D effluents, Phase 3-0 207

110 Total organic carbon (TOC) in raw, filter influent and sand filter effluent locations for the year 1980. 221

111 Three-day simulated distribution system THM (STT3) in raw, filter influent and sand filter effluent locations for the year 1980. 222

112 Total organic carbon (TOC) and three-day simulated distribution system THM (STT3) seasonal service time curves for GAC filters. 224

113 GAC filter carbon use rates, 1980 227

114 GAC filter service lives, 1980. 228

115 Total organic carbon (TOC) carbon use rates for multiple runs of contactors, Phase 3 (TOC=1000 ug/l) 230

116 Total organic carbon (TOC) seasonal service time curves for contactors, Phase 3. 232

117 Three-day simulated distribution system THM (STT3) seasonal service time curves for contactors, Phase 3. 233

118 Contactor carbon use rate, 1980 234

119 Contactor service life, 1980. 235

120 Acid extract profiles for quench and scrubber samples, May 13, 1981 261

121 Acid extract profiles for quench and scrubber samples, May 15, 1981 262

122 THM comparison of actual distribution system (ITTT) vs three-day simulated distribution system (STT3), 1980 264

TABLES

Number		Page
1	Contactor design specifications	27
2	Washwater pump specifications	28
3	Process pump specifications	28
4	Instrument air system specifications.	29
5	Pre-grant costs of establishing organics laboratory	36
6	Laboratory equipment inventory.	38
7	Graphics equipment.	39
8	Actual operating conditions for full-scale GAC systems.	41
9	Actual operating conditions for GAC pilot columns	42
10	Nominal operational parameters for GAC filters.	42
11	Nominal operational parameters for pilot GAC filters.	42
12	Nominal operational parameters for pilot contactors	43
13	Nominal operational parameters for contactors	44
14	Nominal GAC regenerator parameters.	46
15	Phase, run, runday schedule	54
16	Phase 1 sample plan overview.	55
17	Phase 2 sample plan overview.	57
18	Phase 3 sample plan overview.	59
19	GC/MS lower detection limits.	64
20	Analytical methods reference list	67
21	Average percent relative deviation of THM analyses.	68

22 Average percent relative deviation for THM control samples. . . 69

23 USEPA Performance Evaluation Standards WP005, March, 1979 . . . 70

24 USEPA Performance Evaluation Standards WS006, February, 1980. . 71

25 USEPA Performance Evaluation Standards WS008, May, 1981 71

26 USEPA Performance Evaluation Standards, March, 1979 73

27 USEPA Performance Evaluation Standards, April, 1979 74

28 USEPA Performance Evaluation Standards, November, 1979. 75

29 USEPA Performance Evaluation Standards, June, 1980. 76

30 USEPA Performance Evaluation Standards, February, 1981. 77

31 Average percent relative deviation of purgeable non-halogenateds 78

32 TOC results from USEPA Performance Evaluation Standards, WS005. 79

33 Purgeable halogenated organics for GAC Filters 19A and 21A, Phase 1-0. 87

34 Purgeable halogenated organics for GAC Filters 21A and 23A, Phase 1-0. 92

35 Comparison of filter run between GAC filters and plant average. 93

36 Comparison of filter run times during typical period when sand filter runs were less than 60 hours 93

37 Bituminous and lignite GAC characteristics. 104

38 Bituminous and lignite GAC prices 104

39 Comparison of bituminous and lignite pilot contactors for selected exhaustion criteria 104

40 Purgeable halogenated organics for Contactor D level 7 and GAC Filter 15A effluent, Phase 3-0 131

41 Purgeable halogenated organics for Contactor C level 7 and GAC Filter 15A effluent, Phase 3-1 132

42 Purgeable non-halogenated organics for Contactor D level 7 and GAC Filter 15A effluent, Phase 3-0 133

43 Purgeable non-halogenated organics for Contactor C level 7 and GAC Filter 15A effluent, Phase 3-1 134

44 Acid extract compounds tentatively identified by GC/MS from GAC Filter 15A 141

45 Exhaustion criteria for Contactor D level 7 and GAC Filter 15A effluent, Phase 3-0. 143

46 Exhaustion criteria for Contactor C level 7 and GAC Filter 15A effluent, Phase 3-1. 144

47 Acid extract compounds tentatively identified by GC/MS from Contactor D 157

48 Established MCLs for organic compounds. 158

49 Percent removal data summary of Grob CLSA results Contactor A, Phase 3-0, rundays 1 through 134. 159

50 Percent removal data summary of GROB CLSA results Contactor A, Phase 3-0, rundays 162 through 302. 160

51 Average influent concentration for Contactor D and GAC Filter 15A 166

52 Comparison of pilot and full-scale GAC filter systems 173

53 Comparison of pilot and full-scale contactor system 193

54 Application of various exhaustion criteria to GAC Filter 15A and Contactor D, Phase 3-0. 209

55 Application of various exhaustion criteria to GAC Filter 15A and Contactor D, Phase 3-1. 210

56 Application of various exhaustion criteria to GAC Filter 15A and Contactor D, Phase 3-2. 211

57 GAC analysis data 216

58 Comparison of CWW and GIT analyses of GAC characteristics . . . 217

59 Total GAC losses. 218

60 GAC losses across furnace 218

61 Contactor GAC transport losses. 219

62 Sand separator, percent sand in GAC 219

63 GAC filter service lives for selected TOC treatment goals, in days . . . 225

64 GAC filter service lives for selected THMSIMDIST treatment goals, in days . . . 225

65 Contactor service life, in days . . . 231

66 Useful life estimates for capital cost data . . . 240

67 Cost factors . . . 241

68 Detailed capital costs . . . 242

69 Capital cost summary . . . 243

70 Preliminary annual operating and maintenance costs . . . 244

71 Comparison of annual amortized capital cost . . . 245

72 Total annual costs recap . . . 245

73 Unit costs recap . . . 246

74 Operating and maintenance cost factors . . . 247

75 Conceptual design summary for GAC filters . . . 249

76 Cost estimates for full-scale conversion of plant to GAC filters . . . 250

77 Conceptual design summary for contactors . . . 252

78 Cost estimates for full-scale conversion of plant to contactors 253

79 Cost of alternative treatment goals . . . 254

80 Standard plate counts per ml for Phase 3-0 . . . 255

81 Regenerator off-gas analyses results . . . 257

82 Physical, chemical and organic data from May 13, 1981 quench and scrubber samples . . . 258

83 Physical, chemical and organic data from May 15, 1981 quench and scrubber samples . . . 259

84 THMMAX data from May 13 and 15, 1981 quench and scrubber samples . . . 260

ABBREVIATIONS AND SYMBOLS

BET	Brunauer-Emmett-Teller total surface area
BIT	bituminous
BVL	bed volume losses
BTU	British thermal unit
CAOX	carbon adsorbable organohalide
CBE	Chemical Building East
CBW	Chemical Building West
ccf	hundred cubic foot
$CHBr_3$	bromoform
$CHBrCl_2$	bromodichloromethane
$CHBr_2Cl$	dibromochloromethane
$CHCl_3$	chloroform
CLSA	closed loop stripping analysis
CWW	Cincinnati Water Works
cu ft	cubic foot
cu m	cubic meter
cu m/d	cubic meter per day
cu m/s	cubic meter per second
cu yd	cubic yard
DFTPP	decafluorotriphenylphosphine
EBCT	empty bed contact time
EBV	empty bed volume
EF	exhausted freeboard
ELECT	Electrical
EMSL	Environmental Monitoring and Support Laboratory
EWODS	Early Warning Organic Detection System
EXH	exhaustion
ft	foot
GAC	granular activated carbon
gal	gallon
GC	gas chromatograph
GC/FID	gas chromatograph/flame ionization detector
GC/MS	gas chromatograph/mass spectrometer
GIT	Georgia Institute of Technology
gpd	gallon per day
gpd/sq ft	gallon per day per square foot
gpm	gallon per minute

hr	hour
ICI	ICI Americas, Inc.
in	inch
INSTTHM	trihalomethanes present at time of sample collection
k cu m	1000 cubic meter
kg	kilogram
km	kilometer
kPa	kilo Pascals
kWh	kilowatt-hour
lb	pound
LIG	lignite carbon
l	liter
lpd	liter per day
lpd/cu m	liter per day per cubic meter
lpm/sqm	liter per minute per square meter
lps	liter per second
m	meter
MCL	maximum contaminant level
MERL	Municipal Environmental Research Laboratory
mg	milligram
mgd	million gallon per day
mg/l	milligram per liter
mgy	million gallon per year
mi	mile
mil gal	million gallon
min	minute
mph	mile per hour
mt	metric ton
NI	new interface
ng	nanogram
NPSH	net positive suction head
NTU	nephelometric turbidity unit
OEPA	Ohio Environmental Protection Agency
OI	original interface
ORP	Ohio River Plant
ORSANCO	Ohio River Valley Water Sanitation Commission
PAC	powdered activated carbon
PCB	polychlorinatedbiphenyl
PFA	post filter adsorber, pilot columns
pH	index of acidity or alkalinity
psi	pound per square inch
psig	pounds per square inch gauge
PUMP STA	pumping station
RBV	regenerated bed volume
RCC	Regional Computer Center
RESV	reservoir
RF	regenerated freeboard

RV	regenerated/virgin, pilot columns
SCFM	standard cubic foot per minute
sq ft	square foot
sq km	square kilometer
sq m	square meter
sq mi	square mile
ss	stainless steel
ST1	Storage Tank 1
ST2	Storage Tank 2
SWORCC	Southwest Ohio Regional Computer Center
tdh	total dynamic head
THM	trihalomethane
THMFP	trihalomethane formation potential
THMSIMDIST	simulated distribution system trihalomethane
TOC	total organic carbon
ton	short ton
USEPA	United States Environmental Protection Agency
TBE	tetrabromoethane
TFE	polytetrachloroethylene
VMR	volume of material removed
yr	year

ACKNOWLEDGEMENTS

This research project was accomplished through the efforts of many individuals working toward a common goal. Many employees of the Cincinnati Water Works (CWW), although not specifically trained for scientific research, played key roles and contributed greatly to the success of this project. This was a total team effort, with all CWW Divisions participating: the Administration Division for financial control and secretarial support in preparation of the various reports; the Commercial Division for typing and preparation of data for entry into the computer; the Supply Division for construction, maintenance and operation of associated facilities; the Distribution Division for occasional pipe work; the Water Quality and Research Division for conducting the analytical work; and the Engineering Division for design, GAC measurement and graphics activities.

The support and assistance of several people at the U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory (MERL) was greatly appreciated. In particular the advice and guidance of Jack DeMarco, Project Officer, was instrumental in keeping the project on track and goal oriented. Alan A. Stevens, Ronald C. Dressman and Dennis R. Seeger performed some of the acid extracts and organohalide analysis that gave added dimension to the total findings. Frederich C. Kopfler, Robert G. Melton and W. Emile Coleman performed the Grob closed loop stripping analyses, which again broadened the total findings. Analytical training and assistance was provided by the Environmental Monitoring and Support Laboratories (EMSL).

Also much appreciated was the assistance of the Office of Public Water Supply Division of the Ohio Environmental Protection Agency (OEPA) in conducting pesticide, herbicide and PCB analyses.

Additional analytical work was performed under contract by the University of Cincinnati and PEDCo Environmental.

The loan of pilot colums by Westvaco and I.C.I. Americas Inc., which expedited the pilot scale work, was sincerely appreciated.

Design and construction supervision for the contactors and regeneration furnace was performed under contract by Black & Veatch, Consulting Engineers.

Finally, we wish to gratefully acknowledge the significant contributions of the late Aaron A. Rosen, Principal Research Investigator for the project until his untimely death in December, 1979. A noted expert on water pollution and a pioneer in the study of organic contaminants, Dr. Rosen contributed immeasurably to the success and professionalism of this project.

SECTION 1

INTRODUCTION

The Cincinnati Water Works (CWW) serves all of corporate Cincinnati, most of Hamilton County, and a portion of Butler and Warren Counties in Ohio. The water service area covers approximately 1,165 sq km (450 sq mi) and serves more than 860,000 people by means of 195,300 water accounts. Average daily pumping rates are currently 6.1 cu m/s (139 mgd). As such, this system is the largest community water system[1] located on the Ohio River.

Water intakes for the system are located 744.8 km (462.8 mi) downstream from the headwaters of the Ohio River. These headwaters begin at the confluence of the Allegheny and Monongahela Rivers. The uppermost 560 km (350 mi) of the Ohio River and some of its tributaries, particularly the Kanawha River, accommodate many of the nation's chemical industries. Each year, more than 72 billion kg (80 million tons) of coal, petroleum products, grain and chemical products traverse that portion of the river upstream of Cincinnati[2]. The Ohio River is truly a commercial giant subject to a variety of pollutants.

In their concern for water quality, the CWW had previously unilaterally funded research[3] for reducing trihalomethane formation and had also made initial inquiries to expand their research capability and to seek financial assistance at the Federal level. In early 1977, approximately 63.5 metric tons (70 short tons) of carbon tetrachloride were discharged into the Kanawha River and found its way into many water intakes along the Ohio River. This incident gave impetus to concluding these efforts.

On August 3, 1977, a research grant was awarded to CWW by the United States Environmental Protection Agency (USEPA) entitled "Feasibility Study of Granular Activated Carbon Adsorption and On-site Regeneration."

The primary objective of the project was to determine if the use of granular activated carbon (GAC), utilizing either deep bed contactors or conventional depth gravity filters with on-site GAC regeneration, is feasible for removing specific trace organics from Ohio River water while treating it for human consumption. To be considered feasible, the facility had to remove selected organics to a predesignated level at a cost acceptable to the consumers without adversely affecting the level of treatment provided by the existing plant. A secondary objective was the development of plant design and operating parameters for full-scale plant conversion to GAC treatment.

As a result, a three-phase study was designed to accomplish the following comparisons and determinations:

Phase 1, full-scale GAC filters:

- Compare the relative performance of conventional depth gravity GAC filters (sometimes referred to as filter-adsorbers) for organics removal using three different configurations: 45.7-cm (18-in) 12 x 40 GAC with 30.5-cm (12-in) filter sand underlayer, 76.2-cm (30-in) 12 x 40 GAC, and 76.2-cm (30-in) 20 x 50 GAC.

- Determine the need for the 30.5-cm (12-in) layer of filter sand currently required by the OEPA for rapid sand filters that are converted to GAC filters.

- Determine the need for using a GAC mesh size similar to that of sand for the removal of particulate matter in a GAC filter.

Phase 2, pilot-scale GAC filters and pressure contactors:

- Compare the relative performance of virgin GAC and regenerated GAC in pilot columns simulating gravity GAC filters.

- Compare the relative performance of bituminous-based GAC to lignite-based GAC in a pilot column simulating post-filtration contactors (hereinafter referred to as contactors).

- Predict expected performance of full-scale contactors in Phase 3 through operating data and experience gained with pilot columns.

Phase 3, full-scale contactors and GAC filters with on-site GAC regeneration:

- Determine the extent of trace organics removal by full-scale contactors and GAC filters operating concurrently.

- Determine whether a positive correlation exists between results obtained from pilot columns simulating GAC filters and those obtained from actual full-scale GAC filters.

- Determine whether a positive correlation exists between results obtained from pilot columns simulating contactors and those obtained from actual full-scale contactors.

- Compare the performance of GAC filters and contactors after successive regenerations.

- Determine GAC regeneration criteria for full-scale contactors and GAC filters.

- Determine GAC losses under on-site regeneration conditions.

- Determine the costs associated with organics removal by contactors and GAC filters.

- Determine the costs associated with on-site GAC regeneration.

- Determine various facility design parameters for full-scale applications.

Numerous acronyms and abbreviations have been used throughout this report. Their meaning can be found in either the Abbreviations List in the preliminary pages or in the Computerized Data Dictionary in Appendix A.

Volume 1 of this report contains representative figures and tables of data discussed herein; Volume 2 presents figures and tables of other relevant data and contains on microfilm a comprehensive listing of data developed under the cooperative agreement.

SECTION 2

CONCLUSIONS

The conclusions stated below are based solely on the governing conditions and findings of this particular project. Although certain findings may very well apply at other locations, particularly on the Ohio River, the reader is cautioned not to make conclusions that are all-encompassing and may be inappropriate under differing conditions.

1. No turbidity reduction benefit was derived from the requirement of Section 4.2.1.6 in the Recommended Standards for Water Works[4], commonly referred to as the "Ten State Standards" for a 30.5-cm (12-in) sand underlayer to GAC or to the requirement that replacement media be the same effective size as filter sand.

2. Bacterial growth within the GAC filters and contactors was experienced. Harmful bacteria were eliminated by post-chlorination.

3. Post-chlorination would be an absolute necessity if the entire plant were converted to GAC.

4. Bituminous-based GAC outperformed lignite-based GAC with respect to service life, weight of contaminants adsorbed, and cost per weight of contaminants adsorbed.

5. Pilot columns were reasonably predictive of full-scale GAC systems for organics removal.

6. Floc removal by GAC filters had little effect on the carbon's adsorptive ability.

7. The optimum GAC empty bed contact time (EBCT) would be between 7.0 and 15 minutes during annual average conditions and greater than 15 minutes during critical summer conditions.

8. Regeneration restored the GAC to its virgin adsorptive capacity.

9. GAC regeneration losses averaged 15% by volume for ten contactor regenerations and 18.5% by volume for six GAC filter regenerations.

10. No adverse impact from regeneration was experienced relative to air pollution, wastewater discharge or worker environment.

COSTS

Cost conclusions made in this report are based on preliminary estimates using cost curves developed for general application. These cost curves were applied to site-specific design criteria. Actual costs could be considerably different when determined for this or other sites based on a detailed engineering design.

1. The preliminary cost estimates for full-scale design, construction and operation of a GAC system at the CWW treatment plant indicate that a capital investment of approximately $40 million (based on 1981 dollars) may be required to reduce total organic carbon (TOC) concentrations to a specified criterion of 1,000 ug/l using either GAC filters or contactors.

2. A GAC filter system compared to a contactor system will annually cost (in 1981 dollars) about twice as much for operating and maintenance costs ($8.0 vs. $4.0 million) and about 1.5 times as much for total costs, including capital amortization ($12.4 vs. $8.5 million).

3. The estimated increase in the unit production costs of water to reduce finished water from an average of about 2,100 µg/l to a treatment goal of 1,000 µg/l TOC will be $0.06 per cu m ($0.24 per 1,000 gal) for GAC filters (7.5 min EBCT) and $0.04 per cu m ($0.165 per 1,000 gal) for contactors (15.0 min EBCT), all in 1981 dollars.

4. The cost to regenerate GAC on-site over the life of the project averaged about $0.46 per kg ($0.21 per lb).

SECTION 3

RECOMMENDATIONS

1. The contactors used for this project were carbon steel lined with a 20 mil coat of Cook Phenicon 980 Epoxy Phenolic paint. The lining was purported to be resistant to organic leaching and carbon abrasion. This configuration was used in lieu of stainless steel for economic reasons. After two years, the lining failed and parted from the steel. Additional work should be done to identify suitable lining materials or application methods that will produce a longer service life and yet not leach organic contaminants.

2. The sand separator supplied with the regeneration furnace was very inefficient. A more efficient means of separating filter sand from GAC should be developed for sites that use filter conversion to a GAC configuration.

3. Health effects were not a part of this project, therefore, toxicity tests were not conducted. The effectiveness of GAC for removing toxic substances should be determined by performing toxicity tests on influent water and GAC effluent water of various contact times and various stages of carbon exhaustion.

4. Lignite-based GAC was only used in pilot-scale studies during this project. Full-scale use of lignite-based GAC should be conducted to determine the regenerability characteristics and the losses due to transport and regeneration.

5. The hydraulic loading to the contactors was established to obtain a maximum 15 minute EBCT. Carbon use rates for 20 minute EBCT were based solely on extrapolation which indicated no economic advantage. Additional work should be done to establish the optimum EBCT for the CWW which appears to fall somewhere between 7.5 and 20 minutes.

SECTION 4

DESCRIPTION OF THE WATER TREATMENT COMPLEX

The CWW has the Ohio River as its primary water source. The original steam powered pumping station, constructed at the turn of the century, is served by an intake pier situated approximately 100 m (300 ft) from the Kentucky shore (Figure 1). A gravity tunnel beneath the river supplies four 0.7 cu m/s (15 mgd) electric pumps which are the only active units at the River Pumping Station (RS) since the deactivation of the steam plant in 1963. A second raw water pumping station, the electrically powered Ohio River Plant (ORP), was put into service at that time. It too is supplied by a gravity tunnel beneath the river which has a subsurface intake crib located directly upstream from the intake pier. ORP houses four 1,492 kW (2000 hp) electrically driven pumps having a capacity of 3 cu m/s (70 mgd) each. The raw water is conducted from the two low pressure pumping stations through a pair of 1.5 m (60 in) cast iron mains installed at the time of construction of the RS and a single 1.8 m (72 in) concrete main put in service with ORP.

Adjacent to the cast iron mains is Chemical Building West (CBW), a treatment facility, which includes a powdered activated carbon (PAC) storage and slurry feed system, liquid alum storage and feed equipment and four active and one standby 50 metric ton (55 short ton) liquid chlorine storage tanks with a battery of chlorine evaporators, feeders and injection pumps.

From this installation, all feed systems may inject directly into two 1.5 m (60 in) and one 1.8 m (72 in) mains. Chlorine solution and PAC slurry may also be fed at the hydraulic jumps of Chemical Building East (CBE) or at the Filter Plant influent flume from CBW.

The raw water from the pumping stations discharges into two large presettling basins having a combined capacity of 1.4 mil cu m (372 mil gal). This rather unique feature among water plants provides 2 to 3 days retention time. In past years, chlorine was injected into the raw water mains ahead of these basins. A study[3] in 1975 revealed that improved water quality was achieved by moving the point of chlorination downstream from the basins. This resulted in a 75% reduction of THM formation and a 65% reduction of chlorine consumption.

From the two large reservoirs, the water flows through CBE passing through two parallel water turbine powered generators which serve as a velocity breaker while, at the same time, recovering some of the pumping power costs. The turbine discharge flow is split into two hydraulic jumps, thereby providing a rapid mixing of chemicals being fed at that point. CBE

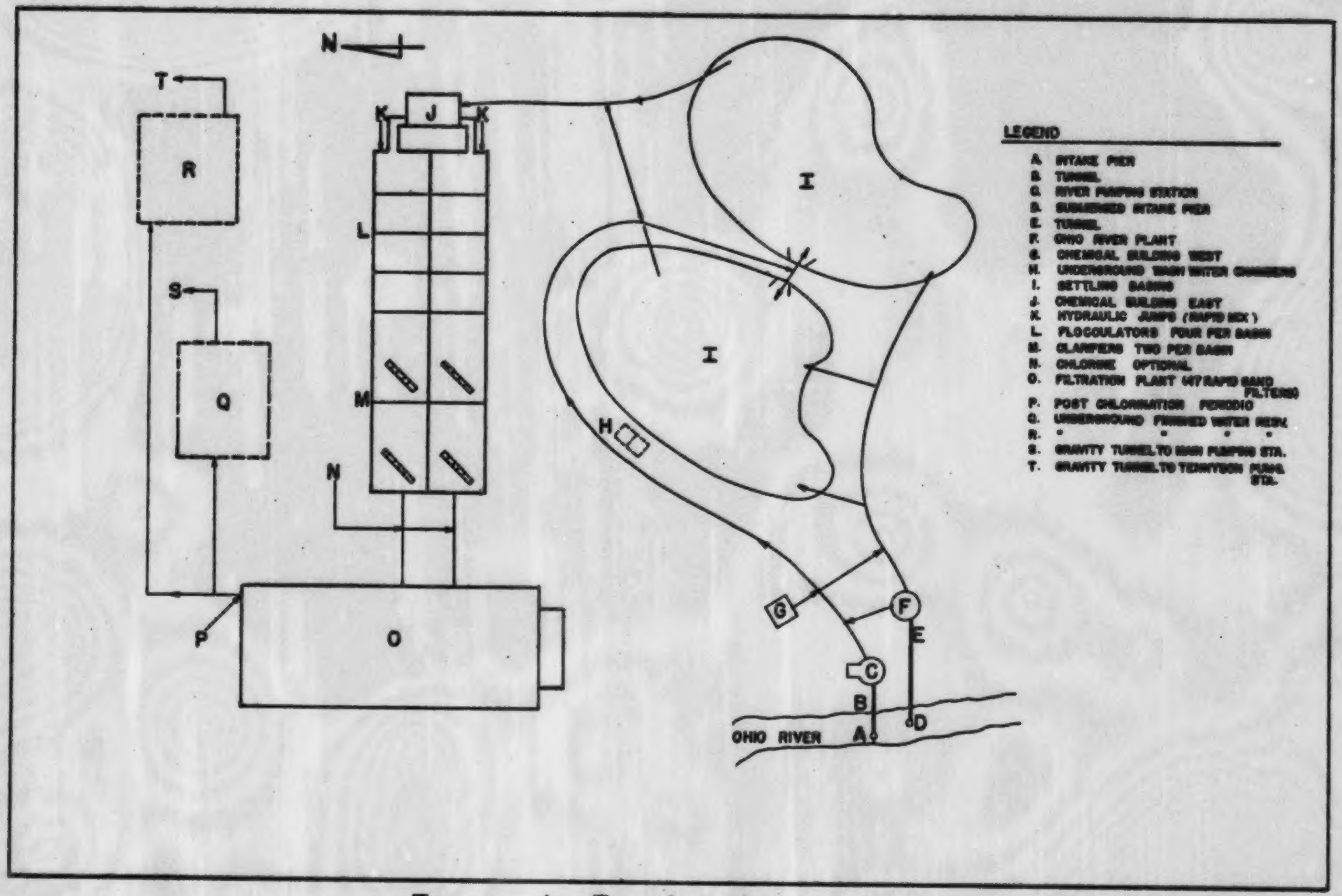

N
T
R
S
Q
P
O
K
J
K
L
M
N
H
I
I
G
F
E
C
B
A
D
OHIO RIVER
LEGEND
A. INTAKE PIER
B. TUNNEL
C. RIVER PUMPING STATION
D. SUBMERGED INTAKE PIER
E. TUNNEL
F. OHIO RIVER PLANT
G. CHEMICAL BUILDING WEST
H. UNDERGROUND WASH WATER CHAMBERS
I. SETTLING BASINS
J. CHEMICAL BUILDING EAST
K. HYDRAULIC JUMPS (RAPID MIX)
L. FLOCCULATORS FOUR PER BASIN
M. CLARIFIERS TWO PER BASIN
N. CHLORINE OPTIONAL
O. FILTRATION PLANT (47 RAPID SAND FILTERS)
P. POST CHLORINATION PERIODIC
Q. UNDERGROUND FINISHED WATER RESV.
R. " " " "
S. GRAVITY TUNNEL TO MAIN PUMPING STA.
T. GRAVITY TUNNEL TO TENNYSON PUMP. STA.

Figure 1. Treatment process.

incorporates a PAC facility equal to that of CBW, lime storage, slaking and feed equipment, ferric sulfate storage and feed, and soda ash storage and feed. From here PAC may be fed directly to the hydraulic jumps or to the raw water mains prior to the presettling basins. Fluoride solution is also fed at the hydraulic jumps.

The hydraulic jumps direct the water to two parallel basins, each containing a flocculation section having a series of four horizontal shaft, paddle wheel flocculators followed by clarification with settled coagulant being collected by two radial sweep boom clarifiers. Each basin has a capacity of 49,215 cu m (13 mil gal).

From the clarifiers, the water enters the Filter Plant through two flumes. The Filter Plant consists of 47 rapid sand gravity filters which are described in detail in a subsequent section of this report. The building also houses a fluoride storage and feed facility and a post chlorination installation supplied by 0.91 metric ton (1 short ton) capacity cylinders.

The plant effluent flume transmits the finished water to either of two underground clearwells. The effluent flume serves as a contact chamber when post chlorination is required.

Clearwell No. 1 was constructed as an open reservoir in the original plant construction (circa 1900) and was covered in the late 1930s. It has a capacity of 86,315 cu m (22.8 mil gal) and primarily serves the Main Pumping Station (MS) through a gravity tunnel. Clearwell No. 2, put into service in the early 1950s, has a capacity of 20,821 cu m (5.5 mil gal) and serves Tennyson Pumping Station (TS)through a separate gravity tunnel. The MS and TS increase the water pressure to provide distribution throughout the system.

Filter backwash water is supplied by two underground reservoirs located adjacent to the presettling basins. They have a combined capacity of 3,500 cu m (0.92 mil gal).

FILTERS

The CWW utilizes the rapid sand filtration method in its treatment process. The Filtration Plant houses 47 filter units, each having an effective area of 130 sq m (1400 sq ft) with a normal operating rate of 1.7 lps/sq m (2.5 gpm/sq ft or 5 mgd).

The filters are of reinforced concrete construction, each comprised of two boxes 4.3 m (14 ft) wide by 15 m (50 ft) long, separated by a 0.76 m (2.5 ft) wide gullet running the long dimension. The gullet serves as the filter influent and backwash discharge flume. A series of four troughs per box conducts the backwash to the gullet and serves to attain uniform effectiveness of the backwash operation. Seven filters, of most recent construction, have the Leopold perforated tile bottoms and surface wash. The other 40 filters have a network of perforated cast iron pipe laterals which conduct the filtered water to collection headers beneath the filter structure.

The filter bed is built up of gradations of gravel and sand in diminishing sizes from bottom to top (Figure 2) as follows: 15.2 cm (6 in) of 3.8 to 6.4 cm (1.5 to 2.5 in) gravel covering the laterals, 12.7 cm (5 in) of 1.9 to 3.8 cm (0.75 to 1.5 in) gravel, 10.2 cm (4 in) of 0.25 to 0.6 cm (0.1 to 0.25 in) pea gravel, 7.6 cm (3 in) of 1.0 mm (0.04 in) torpedo sand, and 76.2 cm (30 in) of 0.45 mm (0.02 in) effective grain size filter sand.

The top surfaces are graded off with the top lip of the troughs as a reference with the clearance termed as freeboard. A finished filter bed initially has a 68.6 cm (27 in) freeboard.

Each filter has an adjacent control panel with switch controls and position indicators for operating the influent, effluent, wash water, and sewer valves. The control panel also has meters showing the rate of flow, loss of head, and elapsed time. The actual rate of flow is accomplished by modulating a discharge valve controlled by pressure differential through a venturi in the effluent pipe.

Large meters indicating the rate of rise for controlling the backwash operation are situated near each end of both filter galleries clearly visible from the filter control panel. Normal plant operation requires backwashing when a head loss of 1.8 m (6 ft) is attained or after 60 hr of service, whichever comes first. The procedure calls for a rate of 12.7 cm or 122 lpm/sq m (5 in or 3 gpm/sq ft of rise) for one min followed by 61 cm or 611 lpm/sq m (24 in of rise or 15 gpm/sq ft) for 3.5 min.

Construction and Modification

For the purpose of this study, five of the Water Treatment Plant's 47 filters were selected in an area (Figure 3) where the most recent filter rebuilding had taken place in order to minimize the possibility of a breakthrough of turbidity during the program. A single concentration of filters was considered desirable to simplify the media transport system and as a convenience in collecting samples (Figure 4).

One empty filter box was set aside for use as a storage facility for regenerated GAC in one half and virgin GAC in the other. Three GAC filters (19A, 21A, 23A) were put into service on February 14, 1978 in Phase 1 of the study using various configurations and GAC types. Another GAC filter (15A) was used during Phase 3 for direct comparison with contactor operation.

No actual structural changes were made to the filters involved, however, some features were added to facilitate the various roles in the study. Foremost of these was the installation of a sample pump which could be selectively connected to stainless steel pipe probes which draw water from the GAC bed. The depth of the inlet ports were adjustable to permit testing of the water quality at any desired level in the GAC bed. Initially the probes were set at the depth of 30.5 cm (1 ft) and at the interface of the GAC and support sand. A third probe in GAC Filters 21A and 23A was set at a depth of 45.7 cm (18 in) in order to get a direct comparison between them and GAC Filter 19A's interface.

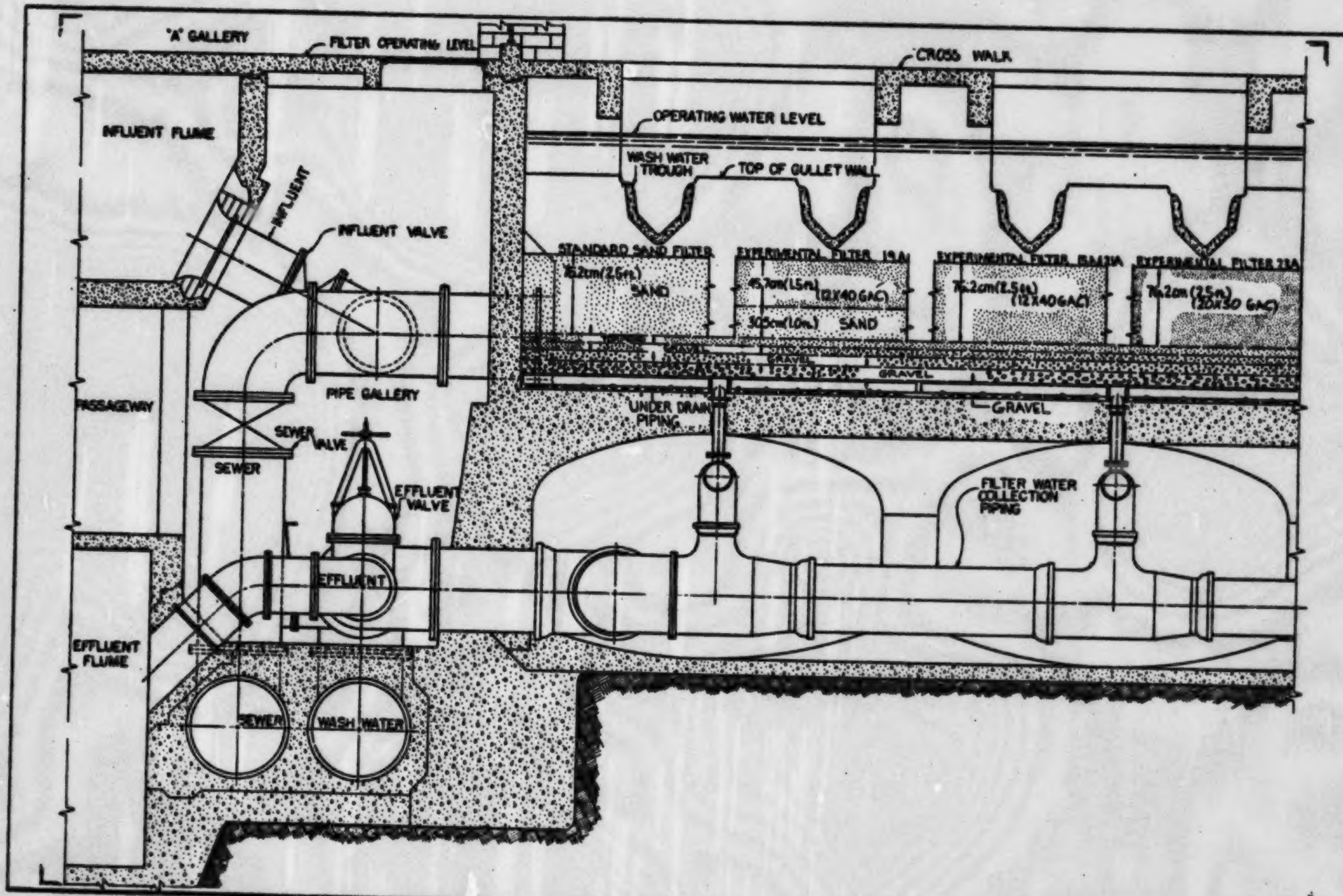

"A" GALLERY
FILTER OPERATING LEVEL
CROSS WALK
INFLUENT FLUME
OPERATING WATER LEVEL
WASH WATER TROUGH
TOP OF GULLET WALL
INFLUENT
INFLUENT VALVE
STANDARD SAND FILTER
76.2cm(2.5ft.)
SAND
EXPERIMENTAL FILTER 19A
45.7cm(1.5ft.)
(12X40 GAC)
30.5cm(1.0ft.)
SAND
EXPERIMENTAL FILTER
76.2cm(2.5ft.)
(12X40 GAC)
EXPERIMENTAL FILTER 23A
76.2cm (2.5ft.)
(20X50 GAC)
GRAVEL
GRAVEL
GRAVEL
PIPE GALLERY
UNDER DRAIN PIPING
GRAVEL
PASSAGEWAY
SEWER VALVE
SEWER
EFFLUENT VALVE
FILTER WATER COLLECTION PIPING
EFFLUENT
EFFLUENT FLUME
SEWER
WASH WATER

Figure 2. Filter and pipe gallery cross-section.

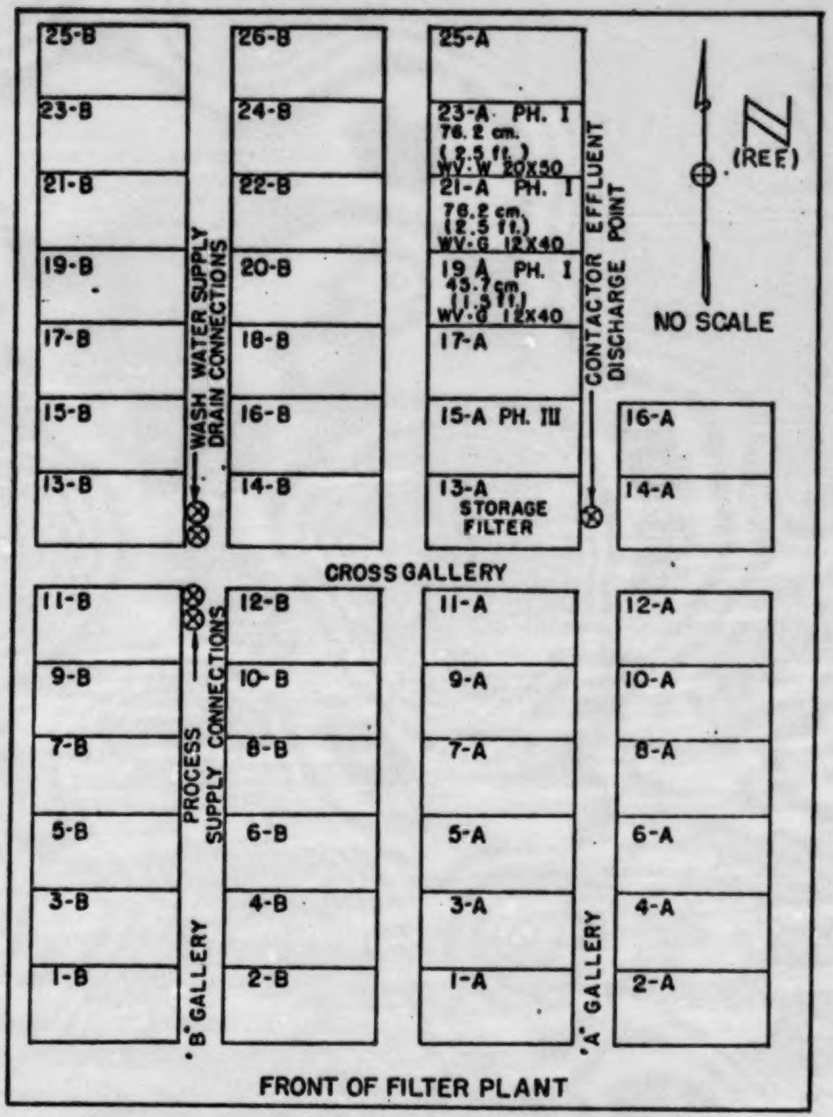

25-B
23-B
21-B
19-B
17-B
15-B
13-B
26-B
24-B
22-B
20-B
18-B
16-B
14-B
WASH WATER SUPPLY
DRAIN CONNECTIONS
25-A
23-A PH. I
76.2 cm.
(2.5 ft.)
WV-W 20X50
21-A PH. I
76.2 cm.
(2.5 ft.)
WV-G 12X40
19 A PH. I
45.7 cm
(1.5 ft.)
WV-G 12X40
17-A
15-A PH. III
13-A
STORAGE
FILTER
CONTACTOR EFFLUENT
DISCHARGE POINT
16-A
14-A
N
(REF)
NO SCALE
CROSS GALLERY
11-B
9-B
7-B
5-B
3-B
1-B
PROCESS
SUPPLY CONNECTIONS
"B" GALLERY
12-B
10-B
8-B
6-B
4-B
2-B
11-A
9-A
7-A
5-A
3-A
1-A
"A" GALLERY
12-A
10-A
8-A
6-A
4-A
2-A
FRONT OF FILTER PLANT

Figure 3. Filter gallery layout.

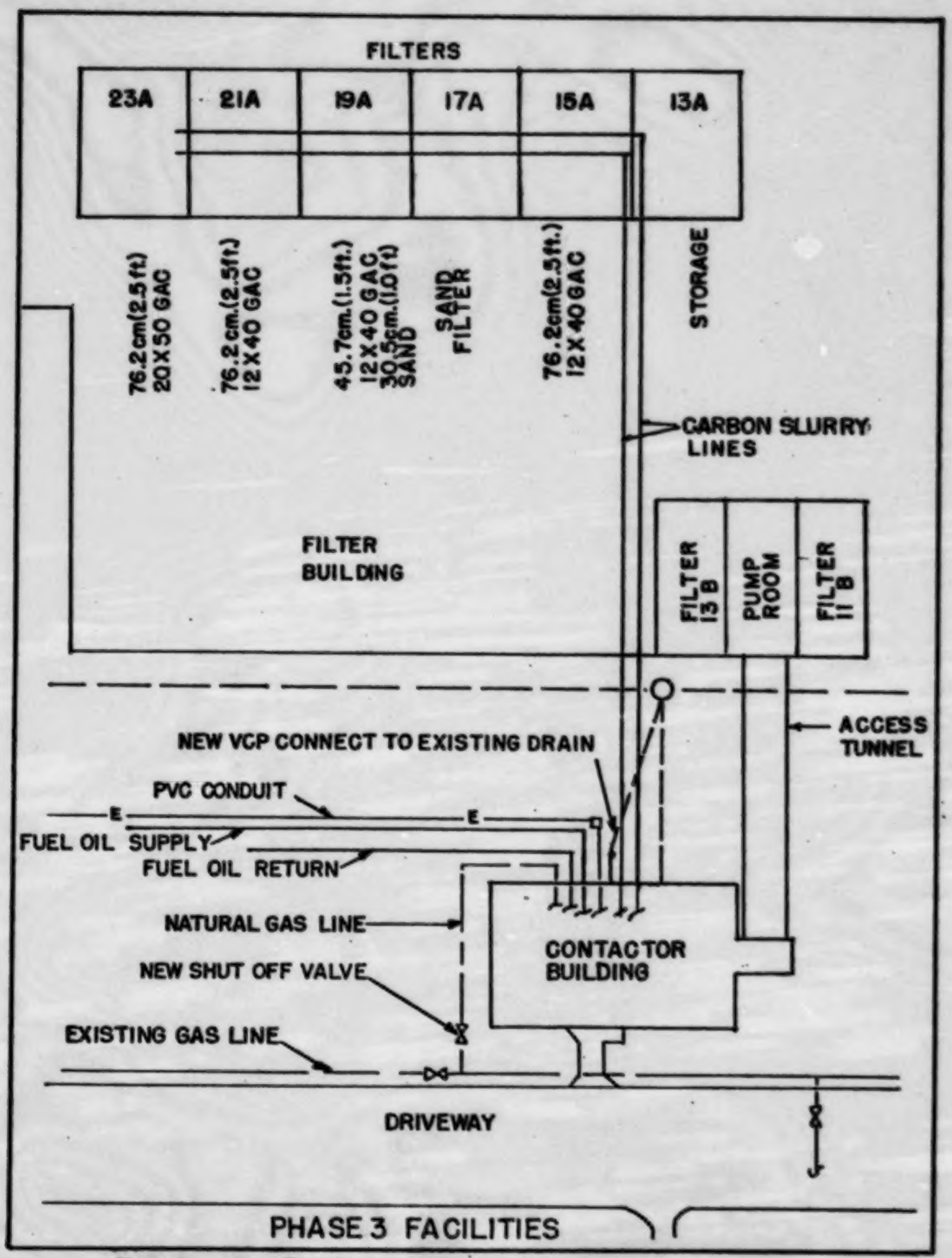

FILTERS
23A
21A
19A
17A
15A
13A
76.2cm(2.5ft) 20X50 GAC
76.2cm.(2.5ft.) 12X40 GAC
45.7cm.(1.5ft.) 12X40 GAC 30.5cm.(1.0ft) SAND
SAND FILTER
76.2cm(2.5ft.) 12X40 GAC
STORAGE
CARBON SLURRY LINES
FILTER BUILDING
FILTER 13 B
PUMP ROOM
FILTER 11 B
ACCESS TUNNEL
NEW VCP CONNECT TO EXISTING DRAIN
PVC CONDUIT
E
E
FUEL OIL SUPPLY
FUEL OIL RETURN
NATURAL GAS LINE
NEW SHUT OFF VALVE
CONTACTOR BUILDING
EXISTING GAS LINE
DRIVEWAY
PHASE 3 FACILITIES

Figure 4. Filter carbon transport piping.

The sample pump, probes, and priming tank are situated on a structural steel frame and grating platform which extends from the walkway out over the filter opening. Safety rails with a kick plate were installed along the heretofore unprotected walkways to permit safe access to the sampling location.

In addition, a connection was tapped into the filter effluent pipe to permit sampling at that point as well as provide a water source for a Hach turbidimeter which continuously monitored and recorded the output quality on a remote recorder located in the laboratory.

Modification of Sand Filter 19A

In view of the fact that the State of Ohio is signatory to the Recommended Standards for Water Works commonly referred to as the "Ten State Standards"[4] for potable water treatment, it was necessary to study one filter structured in compliance with those standards which require a minimum of 30.5 cm (12 in) of filter sand supporting the GAC bed. Accordingly, Filter 19A had only 45.7 cm (18 in) of sand removed and replaced with 45.7 cm (18 in) of Westvaco 12 x 40 WV-G GAC. Filter 19A was taken out of service on March 21, 1980, and the GAC was regenerated during shakedown operation of the furnace. The regenerated GAC was stored for use as make-up GAC. A new 76.2 cm (30 in) bed of filter sand was installed and the filter returned to normal plant service.

Modification of Sand Filter 23A

The Ohio Environmental Protection Agency (OEPA) approved the project contingent upon inclusion of at least one filter containing GAC of the same effective grain size (0.45 to 0.55 mm) as the sand which was removed. While not specifically recommended by the supplier for this application, the 20 x 50 size met the State's requirement. Modifying Filter 23A to comply with this request entailed removal of the 76.2 cm (30 in) deep bed of filter sand, regrading the torpedo sand to establish a 1.5 m (57 in) freeboard and installing 76.2 cm (30 in) of Westvaco 20 x 50 WV-W GAC.

Modification of Sand Filters 21A and 15A

Filter 21A was utilized as a filter adsorber throughout the program while Filter 15A was in use only during Phase 3 for direct comparison to the contactors. In order to obtain the greatest possible contact time for the water passing through the GAC bed, the full 76.2 cm (30 in) bed of filter sand was removed and the torpedo sand screeded off to a uniform 1.5 m (57 in) below the lip of the filter troughs. This was replaced with an equal volume of Westvaco 12 x 40 WV-G GAC. This grade of GAC was recommended by the supplier for a broad spectrum of organic removal.

Modification of Filter 13A

Filter 13A was selected as the GAC storage facility. The top 76.2 cm (30 in) of fine filter sand was removed. A panel of polypropylene mesh of

0.018 cm (0.007 in) filament, having a maximum opening of 0.45 mm, was placed on top of the torpedo sand to serve as a barrier separating the sand from the GAC, thereby preventing mixing or inclusion of the sand when removing the GAC.

Modifications to Filter 11B

Initial discussions provided for the dedication of a single 0.22 cu m/s (5 mgd) filter to supply the water for the contactor process. Filter 11B was selected for this purpose. After considering the effects of a possible turbidity breakthrough of the filter bed and the interruption of supply caused during normal filter backwash operations, this idea was discarded in favor of drawing from Filter Plant "B"-Gallery effluent. In order to accomplish this without structural changes to the effluent flume, it was necessary to remove the existing rate-of-flow controller with its companion square-to-round transition elbow and replace it with one of a current design with a shorter length and standard pipe connections. The elbow was replaced with a tee which provided the additional connecting point as a supply source for the project.

Modifications to Filter 13B

A supply of water for backwashing the contactors was obtained by removing a 76.2 cm (30 in) elbow from the washwater supply to Filter 13B and replacing it with a 76.2 cm (30 in) tee. The additional branch was reduced down to the desired 25.4 cm (10 in) pipe which was then run into the pump room to the suction end of the 82 l/s (1,300 gpm) wash water pump. The discharge piping from the pump was routed through the access tunnel to the contactor building where it joined the multiple manifold network which interconnected contactor influent and effluent lateral systems. The backwash discharge from a contactor was directed to a 25.4 cm (10 in) backwash sewer line header, back through the access tunnel, pump room and into the filter pipe gallery where it was discharged through an existing connection on the plant washwater sewer system at Filter 13B.

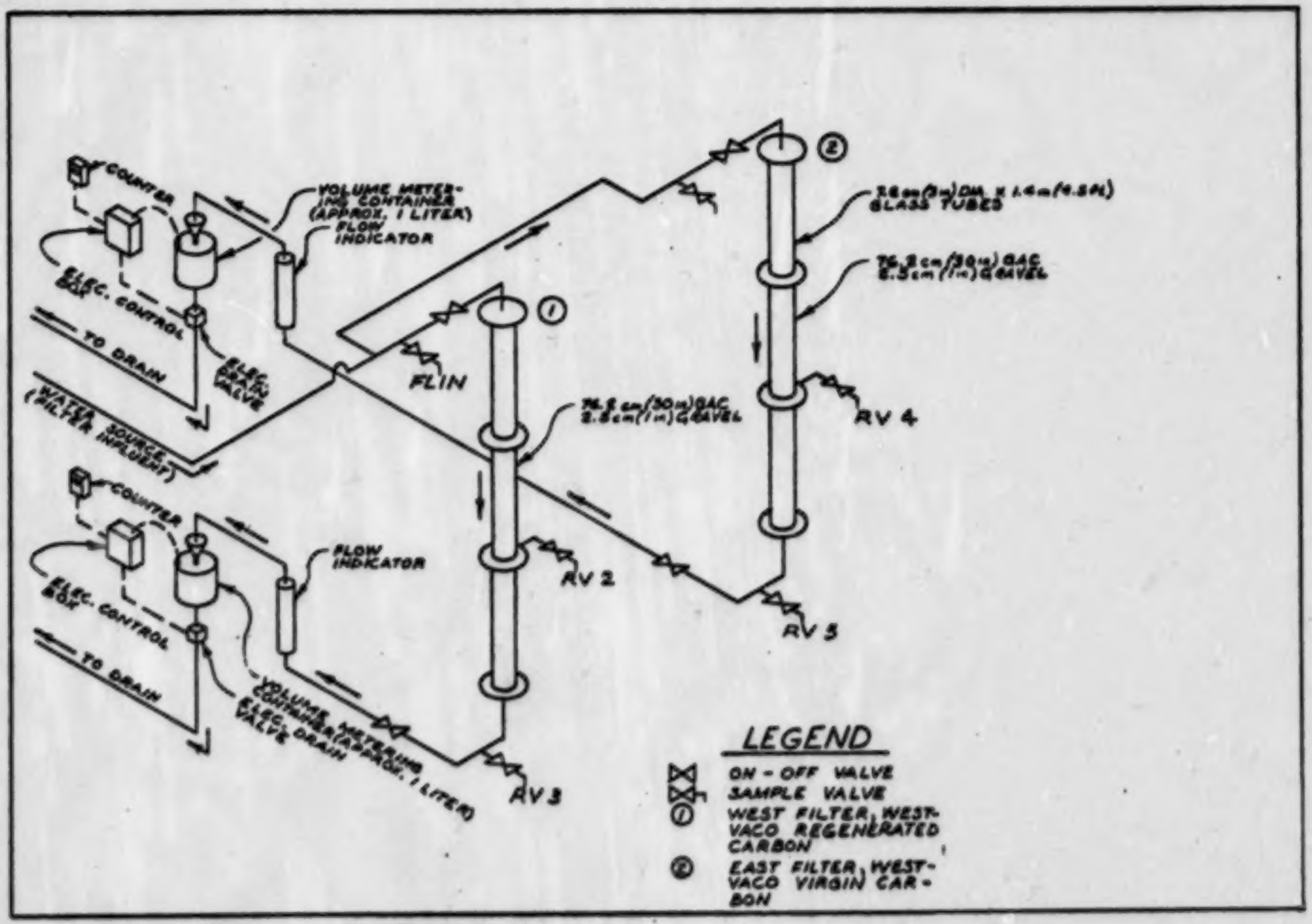
PILOT COLUMNS

Description of 7.6 cm (3 in) Diameter Pilot Columns

Two units of 7.6 cm (3 in) diameter pilot columns were utilized during the course of the project (Figures 5 and 6). The two units were operated with a 76.2 cm (30 in) column of Westvaco 12 x 40 WV-G GAC.

Three glass tube sections of 45.7 cm (18 in) length were coupled together with companion flanges, resulting in a single tube of 1.4 m (54 in). A conical cap was fabricated to close the top to assure even flow over the cross section and eliminate dead space where filtrate may be trapped while being backwashed.

Between the flanges connecting the bottom and second sections a stainless steel ring was inserted. This was drilled through radially, the inside



COUNTER
ELEC. CONTROL BOX
ELEC. DRAIN VALVE
VOLUME METERING CONTAINER (APPROX. 1 LITER)
FLOW INDICATOR
TO DRAIN
WATER SOURCE (FILTER INFLUENT)
FLIN
①
②
7.6cm(3in)DIA x 1.4m(4.5ft) GLASS TUBES
76.2cm(30in)GAC 2.5cm(1in)GRAVEL
76.2cm(30in)GAC 2.5cm(1in)GRAVEL
RV 4
RV 2
RV 5
RV 3
COUNTER
ELEC. CONTROL BOX
FLOW INDICATOR
VOLUME METERING CONTAINER (APPROX. 1 LITER)
ELEC. DRAIN VALVE
TO DRAIN
LEGEND
ON - OFF VALVE
SAMPLE VALVE
① WEST FILTER, WEST-VACO REGENERATED CARBON
② EAST FILTER, WEST-VACO VIRGIN CARBON

Figure 5. Pilot GAC filters, processing flow.

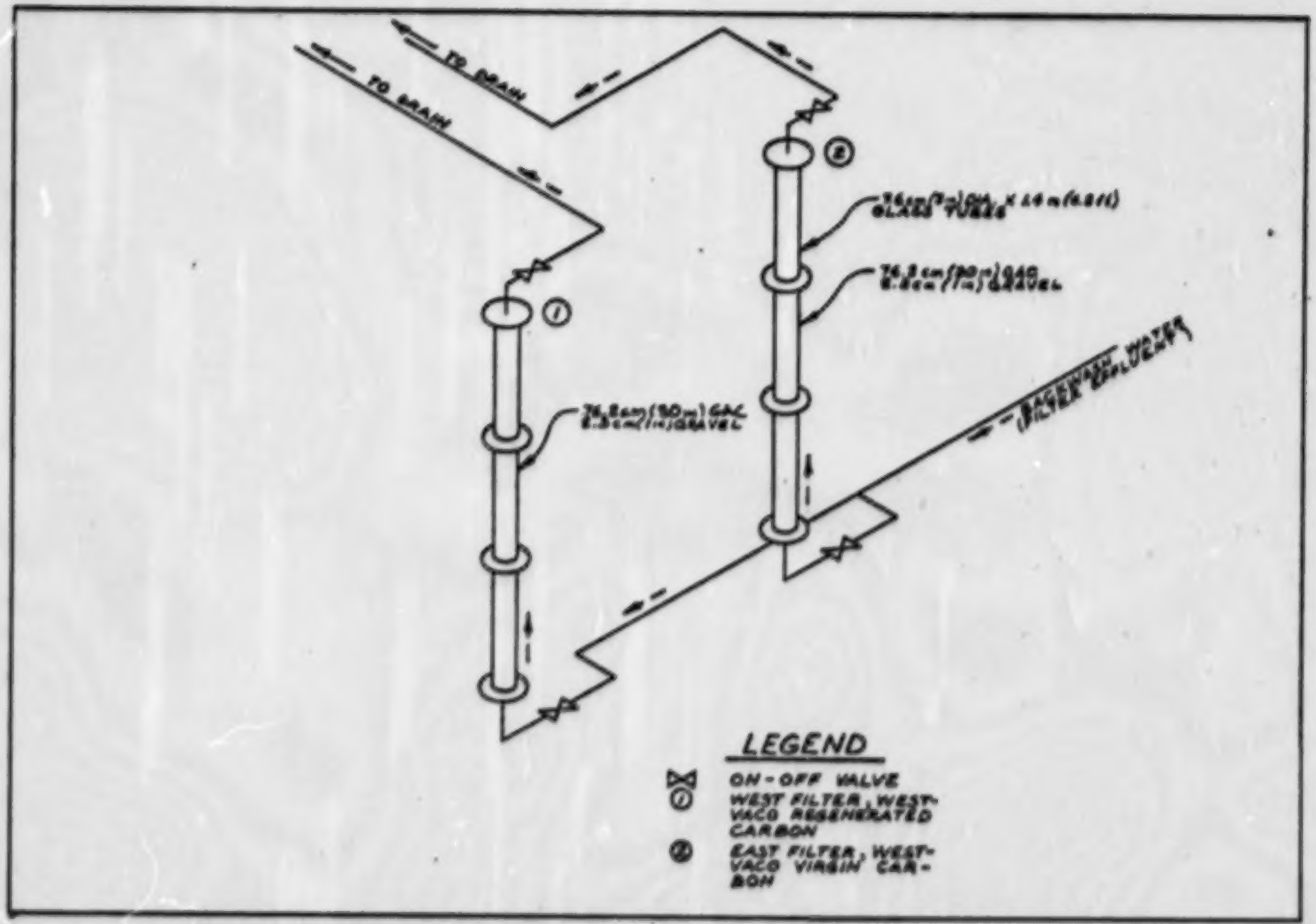

TO DRAIN
TO DRAIN
①
②
7.6cm(3in)DIA. x 1.4 m (4.5 ft) GLASS TUBES
76.2cm(30in)GAC 2.5cm(1in)GRAVEL
76.2cm(30in)GAC 2.5cm(1in)GRAVEL
BACKWASH WATER (FILTER EFFLUENT)
LEGEND
ON-OFF VALVE
① WEST FILTER, WEST-VACO REGENERATED CARBON
② EAST FILTER, WEST-VACO VIRGIN CAR-BON

Figure 6. Pilot, GAC Filters, backwashing flow.

opening was fitted with a fine-screened sample probe, while the outer opening provided a sample line connection referred to as Regenerated/Virgin (RV) for identification of samples. By regulating the depth of the supporting gravel, this port could match the contact time of a 45.7 cm (18 in) deep GAC filter bed.

The bottom was capped with a flat plate drilled for a pipe connection at the center. A fine mesh screen covered the bottom to prevent breakthrough of GAC. An influent valve and backwash waste valve at the top connection in conjunction with an effluent valve and backwash supply valve at the bottom connection made possible complete simulation of filter operation.

The columns were mounted on a plywood panel with the effluent directed to a container which was emptied through a solenoid valve when sensing electrodes determined that the container was full. The flow for the entire operation was calibrated and the number of cycles recorded by an automatic counter.

Feed was intended to be regulated through a rotameter mounted on the board with the column. Due to the limited available head, the added headloss caused by the rotameter was too great to yield the desired throughput so it was bypassed.

Description of the Lignite 10.2 cm (4 in) Pilot Column

The pilot column, loaned by ICI Americas, Inc. for testing their Hydrodarco 1030 GAC product, consisted of five tubes of 10.2 cm (4 in) diameter and 1.8 m (6 ft) length (Figures 7 and 8). They were mounted side-by-side on a free-standing framework of Unistrut-type channel. Both ends of each tube were capped. The top cap had a quick-connect gauge fitting and a two-valved fitting for connections for process and backwash flow. The first tube in the process sequence was fitted with a dead weight safety valve. The lower end had only the connector with the two valves, one for process flow and the other for backwash flow. Inside the column, the port opening was fitted with a Johnson well screen to prevent loss of GAC. Pea gravel, 3 x 6 mm (1/8 x 1/4 in) was placed in the tube to a depth of 2.5 cm (1 in) above the screen.

Four of the tubes were connected in series, with the interconnecting tubing running from the bottom of one to the top of the next, resulting in downward flow through each. The first tube in the sequence had 0.9 m (3 ft) of GAC, each of the three successive tubes had 1.2 m (4 ft) of GAC, for a cumulative column depth of 4.6 m (15 ft), which equals that of the contactors. A sample valve was spliced into each length of the series piping providing intermediate points for collecting samples identified as post filter adsorbers (PFAs).

The fifth 10.2 cm (4 in) tube was completely filled with GAC to give the maximum contact time possible. This tube was utilized to treat the backwash water for the four process tubes so as not to load the tubes with

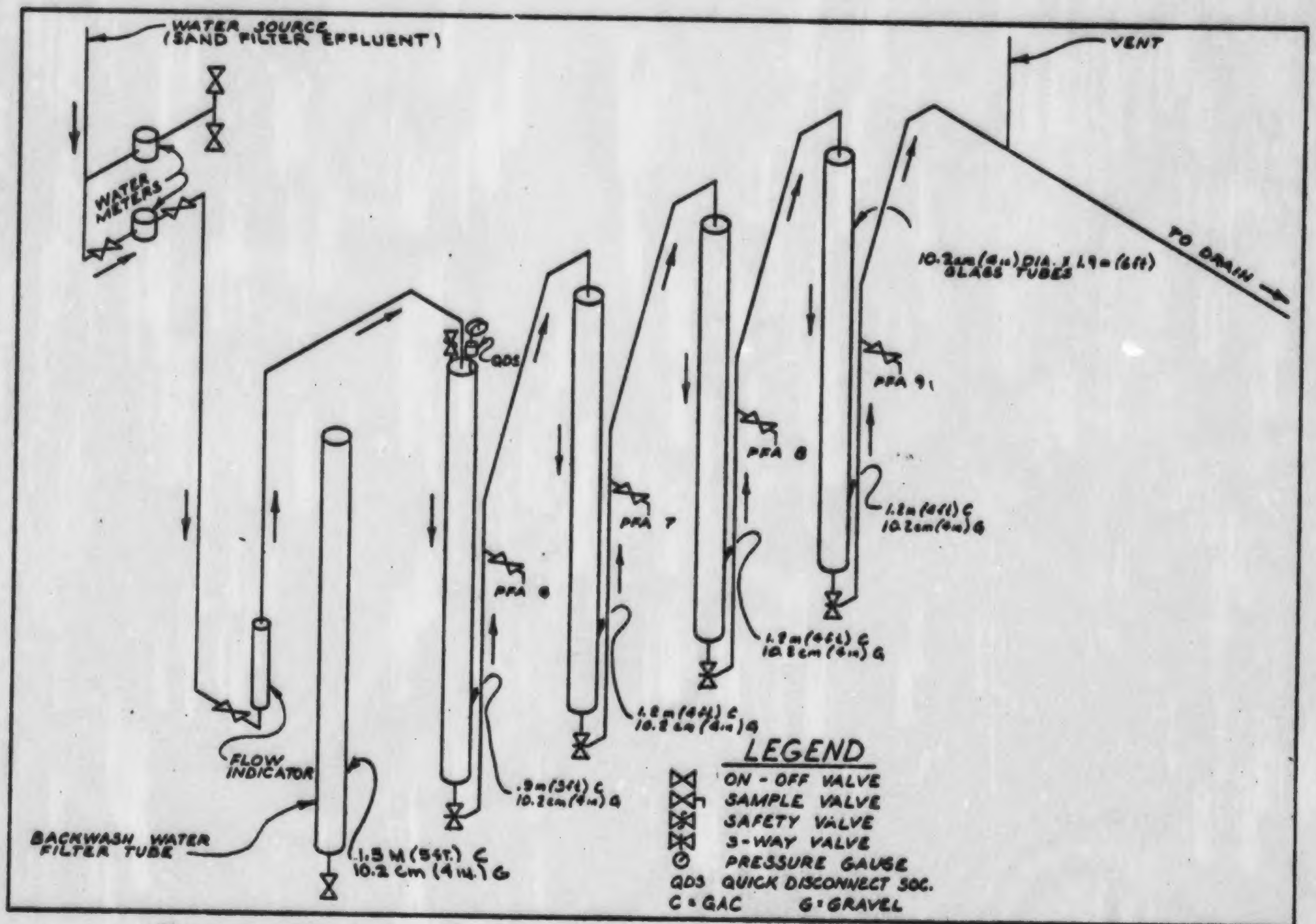

WATER SOURCE
(SAND FILTER EFFLUENT)
WATER METERS
VENT
TO DRAIN
10.2cm(4in) DIA. x 1.9m (6ft)
GLASS TUBES
FLOW INDICATOR
BACKWASH WATER
FILTER TUBE
1.5 M (5ft.) C
10.2 Cm (4 in.) G
QDS
PFA 6
.9m(3ft) C
10.2cm(4in) G
PFA 7
1.2m(4ft) C
10.2cm(4in) G
PFA 8
1.2m(4ft) C
10.2cm(4in) G
PFA 9
1.2m(4ft) C
10.2cm(4in) G
LEGEND
ON - OFF VALVE
SAMPLE VALVE
SAFETY VALVE
3-WAY VALVE
PRESSURE GAUGE
QDS QUICK DISCONNECT SOC.
C = GAC
G = GRAVEL

Figure 7. Lignite pilot contactor, processing flow.

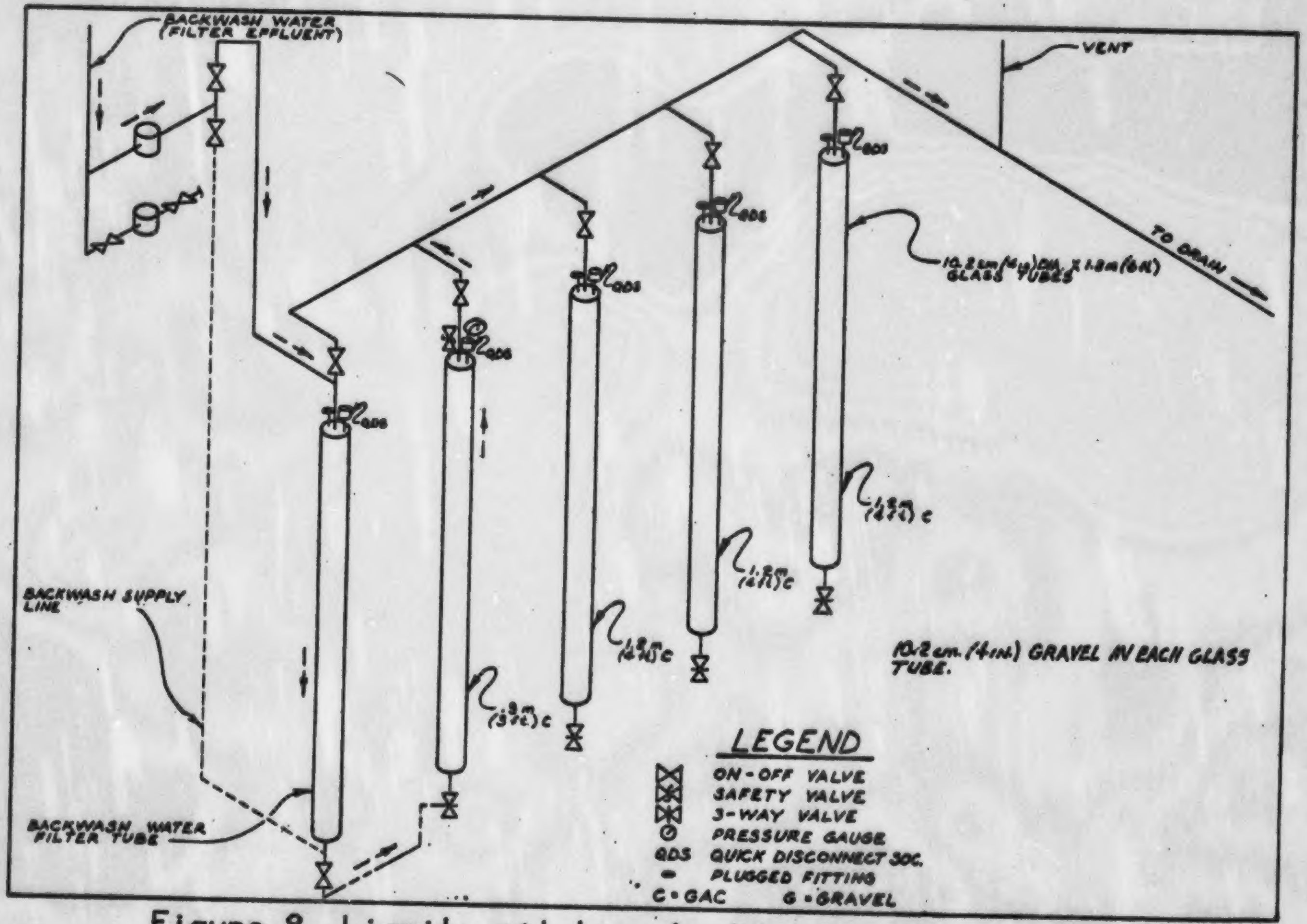

BACKWASH WATER (FILTER EFFLUENT)
VENT
TO DRAIN
10.2 cm (4 in) DIA. x 1.8 m (6 ft) GLASS TUBES
QDS
1.2 m (4 ft) C
1.2 m (4 ft) C
1.2 m (4 ft) C
.9 m (3 ft.) C
BACKWASH SUPPLY LINE
BACKWASH WATER FILTER TUBE
10.2 cm. (4 in.) GRAVEL IN EACH GLASS TUBE.
LEGEND
ON-OFF VALVE
SAFETY VALVE
3-WAY VALVE
PRESSURE GAUGE
QDS QUICK DISCONNECT SOC.
PLUGGED FITTING
C = GAC
G = GRAVEL

Figure 8. Lignite pilot contactor, backwashing flow.

organics from the bottom. The effluent was connected individually and selectively to the valved connection provided at the bottom of each of the four tubes. Influent flows were regulated by a rotameter and total throughput indicated on a standard water meter in the supply line.

Description of the Bituminous GAC 10.2 cm (4 in) Pilot Column

The GAC column was comprised of four 1.5 m (5 ft) sections of 10.2 cm (4 in) diameter glass tubes (Figures 9 and 10). These were mounted side-by-side on a plywood panel board affixed to a free-standing frame.

Each tube was capped on both ends with a blind flange which was drilled and tapped to receive the required fittings. Each end was piped and valved to permit downflow for process use and upflow for backwash mode. Process piping connected the four tubes in series from the outlet at the bottom of the first one to the inlet at the top of the next, continuing through the sequence of the four tubes. Each series pipe had two branch connections, one for a PFA sample tap and the other for a pressure gauge, all of which were mounted on the board adjacent to their respective tubes. There was a pressure gauge on the influent line to the first tube and a dead weight safety valve on the cap of the first tube. Flow rates were controlled by a rotameter mounted on the face of the board. Total throughput was indicated on a wall-mounted water meter.

The tubes were charged with Westvaco WV-G 12 x 40 GAC. The first tube contained 0.9 m (3 ft) of GAC while each of the three succeeding tubes contained 1.2 m (4 ft), giving a cumulative column depth of 4.6 m (15 ft). Rather than make all four tubes equal at 1.1 m (45 in), the existing configuration was established to provide ample freeboard for expansion during backwash of the first tube which, in effect, is the top portion of the GAC column and would entrain all of the suspended matter. A fine mesh screen and shallow gravel bed supported the GAC in each tube.

CONTACTORS

Description

Four contactor tanks were placed in the south half of the contactor building (Figure 11). Each contactor unit was basically a cylindrical shell construction of 9.55 mm (3/8 in) thick carbon steel plate (Figure 12). The ends were closed with standard ASME flanged and dished heads. At the lower end of the cylindrical section, a pipe was welded in place. The exposed flanged end served as the connecting point for the effluent system (downflow mode). There was a short flanged length projecting into the tank. A 20.3 cm (8 in) stainless steel pipe was bolted to that flange and extended diametrically across the tank with its free end being capped and supported by an angle iron cradle welded to the interior wall. This was the header to which eight flanged, stainless steel laterals, arranged into four horizontally opposed pairs, were connected. The lateral pipes had varying lengths dictated by the curvature of the contactor tank shell. Each lateral had a pattern of 2.5 cm (1 in) diameter holes drilled through its wall equally

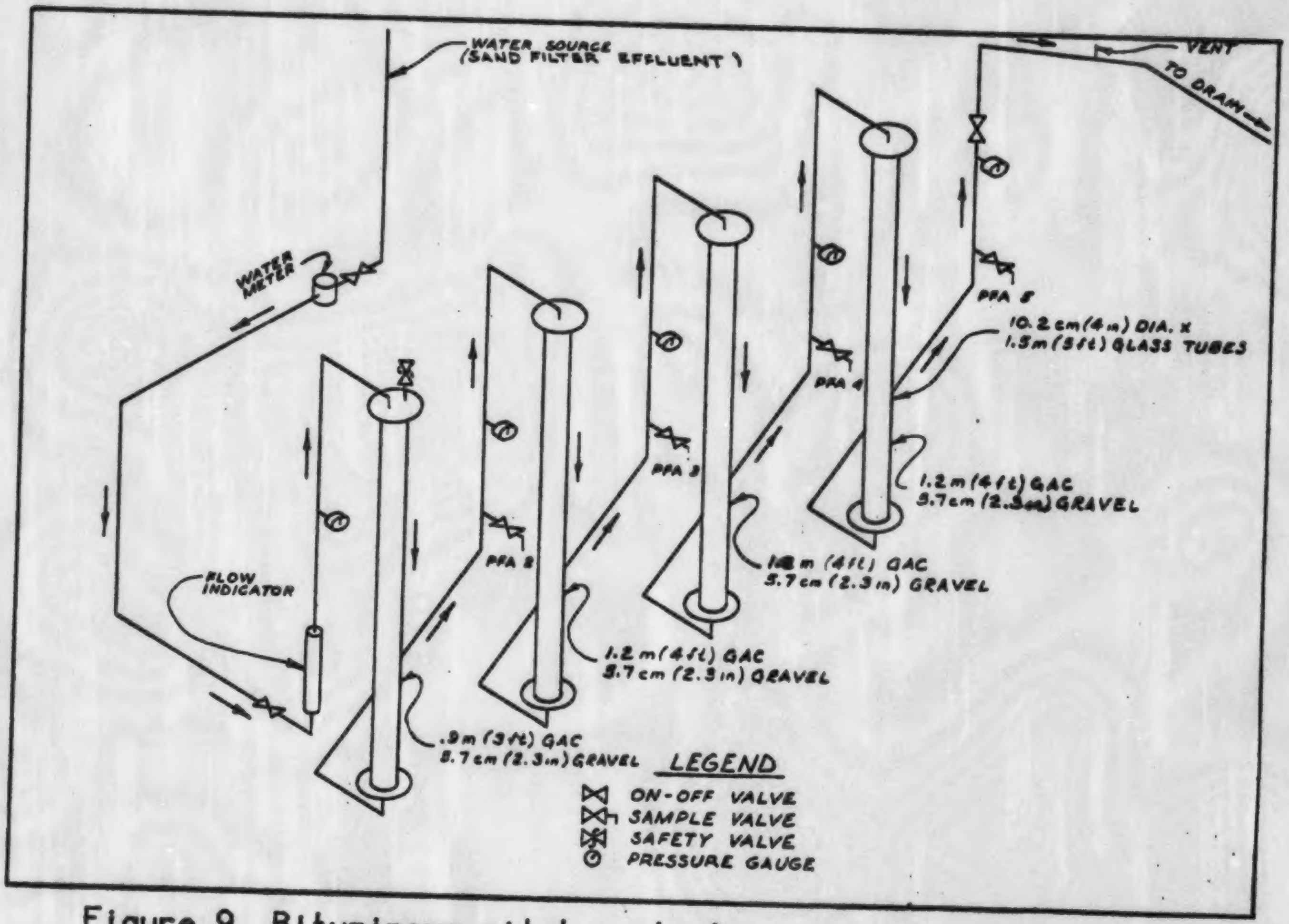

WATER SOURCE (SAND FILTER EFFLUENT)
VENT
TO DRAIN
WATER METER
PFA 5
10.2 cm (4 in) DIA. x 1.5 m (5 ft) GLASS TUBES
PFA 4
1.2 m (4 ft) GAC 5.7 cm (2.3 in) GRAVEL
PFA 3
1.2 m (4 ft) GAC 5.7 cm (2.3 in) GRAVEL
PFA 2
1.2 m (4 ft) GAC 5.7 cm (2.3 in) GRAVEL
FLOW INDICATOR
.9 m (3 ft) GAC 5.7 cm (2.3 in) GRAVEL
LEGEND
ON-OFF VALVE
SAMPLE VALVE
SAFETY VALVE
PRESSURE GAUGE

Figure 9. Bituminous pilot contactor, processing flow.

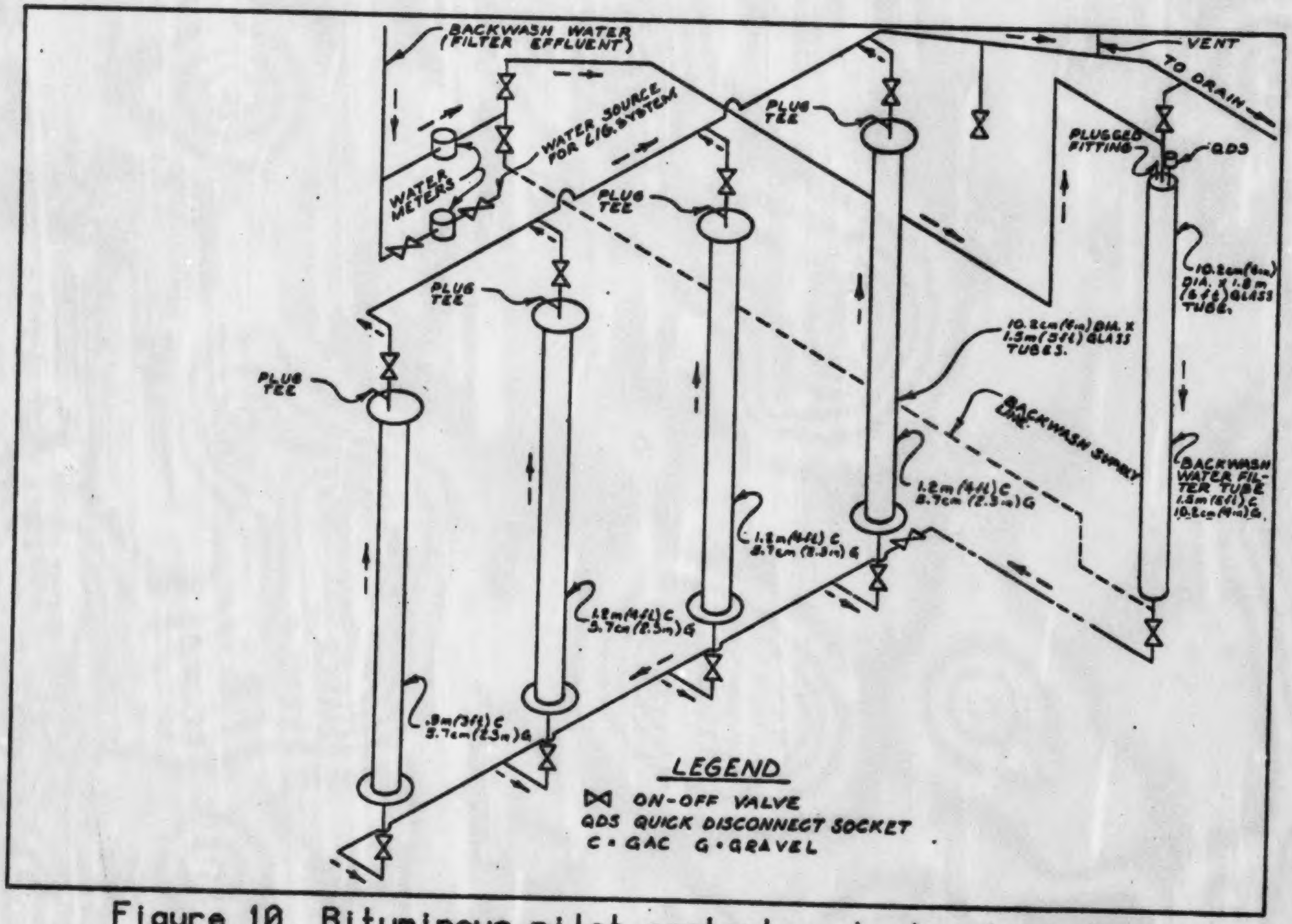

BACKWASH WATER (FILTER EFFLUENT)
WATER METERS
WATER SOURCE FOR C.I.G. SYSTEM
PLUG TEE
PLUG TEE
PLUG TEE
PLUG TEE
VENT
TO DRAIN
PLUGGED FITTING
QDS
10.2cm(4in) DIA. X 1.8m (6ft) GLASS TUBE.
10.2cm(4in) DIA. X 1.5m (5ft) GLASS TUBES.
BACKWASH SUPPLY LINE.
BACKWASH WATER FILTER TUBE 1.5m (5ft) C 10.2cm (4in) G.
1.2m (4ft) C 5.7cm (2.3in) G
1.2m (4ft) C 5.7cm (2.3in) G
1.2m (4ft) C 5.7cm (2.3in) G
.9m (3ft) C 5.7cm (2.3in) G
LEGEND
⋈ ON-OFF VALVE
QDS QUICK DISCONNECT SOCKET
C = GAC G = GRAVEL

Figure 10. Bituminous pilot contactor, backwashing flow.

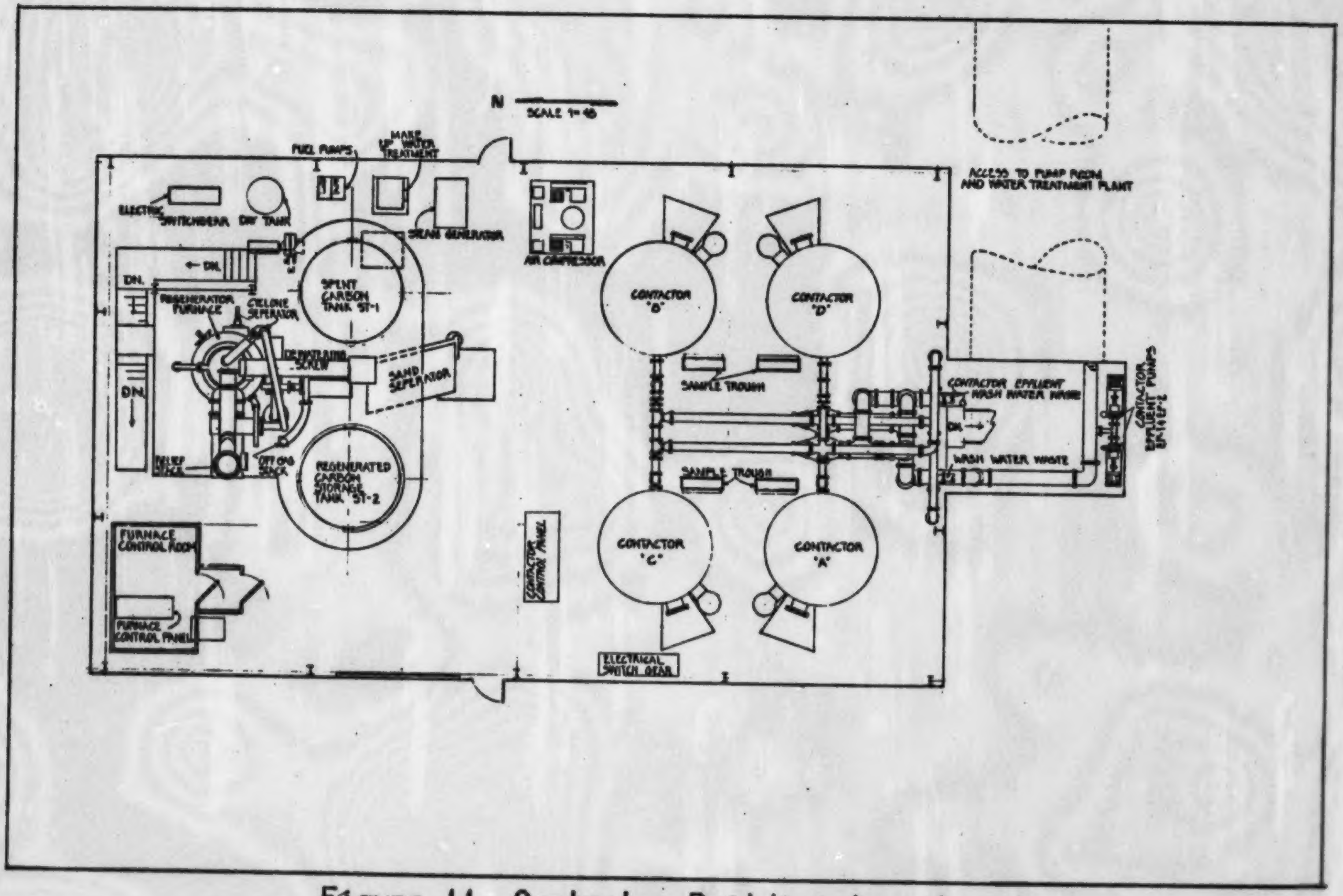

N
SCALE 1"=10'
FUEL PUMPS
MAKE UP WATER TREATMENT
ELECTRIC SWITCHGEAR
DAY TANK
STEAM GENERATOR
AIR COMPRESSOR
DN.
← DN.
DN. ↓
REGENERATOR FURNACE
CYCLONE SEPERATOR
SPENT CARBON TANK ST-1
DEWATERING SCREW
SAND SEPERATOR
RELIEF STACK
OFF GAS STACK
REGENERATED CARBON STORAGE TANK ST-2
FURNACE CONTROL ROOM
FURNACE CONTROL PANEL
CONTACTOR CONTROL PANEL
CONTACTOR "B"
CONTACTOR "D"
CONTACTOR "C"
CONTACTOR "A"
SAMPLE TROUGH
SAMPLE TROUGH
ELECTRICAL SWITCH GEAR
ACCESS TO PUMP ROOM AND WATER TREATMENT PLANT
CONTACTOR EFFLUENT WASH WATER WASTE
DN. →
WASH WATER WASTE
CONTACTOR EFFLUENT PUMPS EP-1 & EP-2

Figure 11. Contactor Building layout.

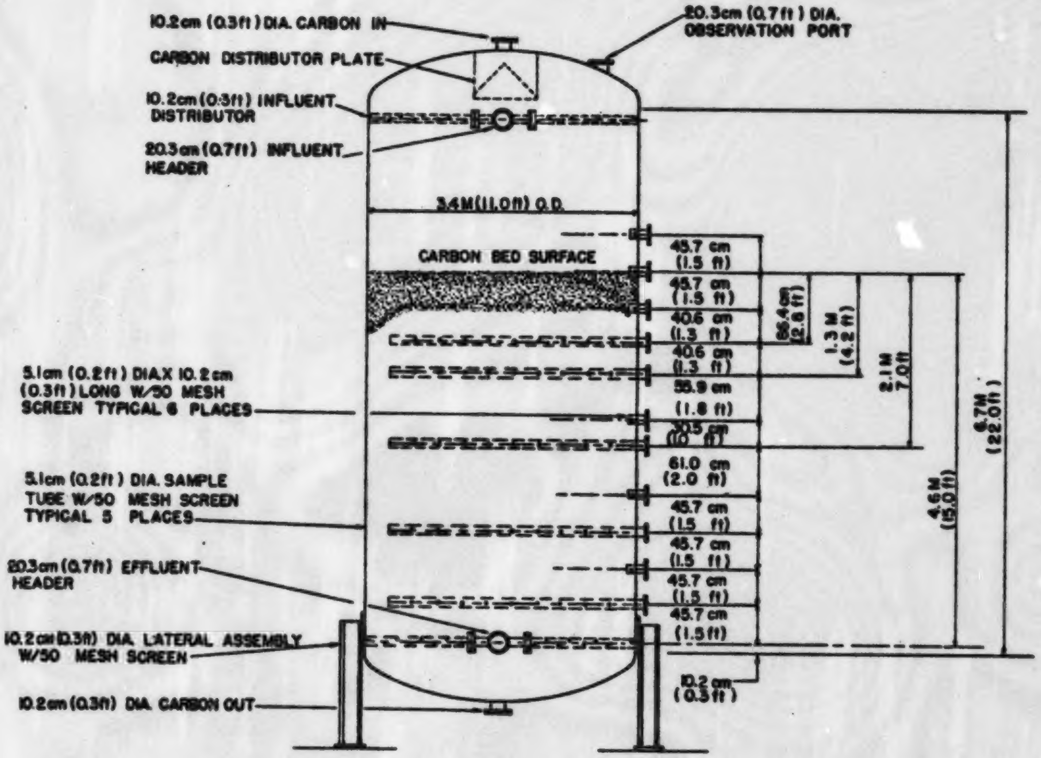

10.2cm (0.3ft) DIA. CARBON IN
CARBON DISTRIBUTOR PLATE
10.2cm (0.3ft) INFLUENT DISTRIBUTOR
20.3cm (0.7ft) INFLUENT HEADER
20.3cm (0.7 ft) DIA. OBSERVATION PORT
3.4M (11.0ft) O.D.
CARBON BED SURFACE
5.1cm (0.2ft) DIA X 10.2cm (0.3ft) LONG W/50 MESH SCREEN TYPICAL 6 PLACES
5.1cm (0.2ft) DIA. SAMPLE TUBE W/50 MESH SCREEN TYPICAL 5 PLACES
20.3cm (0.7ft) EFFLUENT HEADER
10.2cm (0.3ft) DIA. LATERAL ASSEMBLY W/50 MESH SCREEN
10.2cm (0.3ft) DIA. CARBON OUT
45.7 cm (1.5 ft)
45.7 cm (1.5 ft)
40.6 cm (1.3 ft)
40.6 cm (1.3 ft)
55.9 cm (1.8 ft)
30.5 cm (1.0 ft)
61.0 cm (2.0 ft)
45.7 cm (1.5 ft)
45.7 cm (1.5 ft)
45.7 cm (1.5 ft)
45.7 cm (1.5 ft)
10.2 cm (0.3 ft)
85.4 cm (2.8 ft)
1.3 M (4.2 ft)
2.1 M 7.0 ft
4.6 M (15.0 ft)
6.7M (22.0ft)

Figure 12. Contactor cross-section.

spaced in seven annular rings with three holes radially 120 degrees apart in each ring. About each lateral was a 50 mesh stainless steel screen sleeve secured by stainless steel hose clamps. Directly above this arrangement was an identical header/lateral system. The centerlines of the two systems have a vertical separation of 6.5 m (21.2 ft). This provided the external connection for the influent piping. The separation was calculated to permit a 50 percent expansion of the 4.6 m (15 ft) deep GAC bed when backwashed.

A series of 10.2 cm (4 in) flanged pipe stubs which projected from the outer face of the tank were along a vertical line 90 degrees from the influent/effluent connections. The purpose and position of these sample taps were dictated by the analytical requirements of the program, basically on 45 cm (1.5 ft) increments through the GAC bed with some variations to match the contact time experienced at the sample points in the converted sand filters. Not all taps were utilized on a continuous basis. Five prime points were equipped with probes which extended across the full diameter of the bed to assure a representative sample of the water. The sample probe was a 5.1 cm (2 in) pipe with a pattern of twenty holes 6 mm (1/4 in) in diameter and having a 50 mesh screen sleeve in the same manner as a lateral. The remaining sample ports were fitted with short stubs with only six holes and a screen sleeve in the same fashion. These projected only 12 cm (4.75 in) into the bed. Each contactor had its own sample sink with individual faucets connected to the five primary sample taps.

Each tank had a "GAC carbon-in" connection at the center of the top head, and just below it a cone which distributed incoming GAC and protected the influent lateral system. At the top of each tank was an air/vacuum release which vented air as the tank was being filled and admitted air when it was being drained. A steel ladder, with safety cage extending the full height of the tank, provided access to a 50.8 cm (20 in) manway which was located on the side of the tank above the fully charged GAC bed level. Each tank was supported by four wide flanged (WF) structural steel legs. Specifications for the contactor tanks are shown in Table 1.

Although the "A", "B", "C", and "D" labeling on the tanks and instrumentation appears to be random, it was not. This resulted from the identification being assigned in the order that each unit became available from the installing contractor and put into service.

Each tank had a 7.6 cm (3 in) ball valve at the top and bottom GAC transport connections. From the bottom or carbon-out connection, the 7.6 cm (3 in) line joined an overhead common line or header. No increase in size was necessary since only one unit at a time was discharged into it and a constant velocity was desirable. In the same manner, the carbon-in port at the top was connected to the 7.6 cm (3 in) carbon-in header.

Contactors could be charged directly from the GAC tank truck, the regenerated GAC storage tank or the make-up GAC filter (13A). Each contactor carbon-in valve control was a pneumatic cylinder operated valve.

TABLE 1. CONTACTOR DESIGN SPECIFICATIONS

Diameter	3.4	m (11 ft)
Vertical Sidewall Height	6.7	m (22 ft)
GAC Depth	4.6	m (15 ft)
Design Capacity	0.04	cu m/s (1.0 mgd)
Hydraulic Loading	285	lpm/sq m (7.4 gpm/sq ft)
Contact Time	15.3	min
Design Pressure	517.1	kPa (75 psig)
Test Pressure	620.5	kPa (90 psig)
Backwash Hydraulic Loading	407	lpm/sq m (10.0 gpm/sq ft)

Spent GAC was removed from the contactors and transferred to the spent GAC storage tank. The GAC slurry consistency was maintained at 10-15% to transfer in or out of the contactors. Water injection nozzles were welded into the GAC transport pipes to accomplish this. The carbon-out valves were pneumatic cylinder operated valves. Control for the valves were the same as the carbon-in valves.

The lower lateral collector flange of each tank was connected to three elevated headers, one 25.4 cm (10 in) washwater supply line and two 40.6 cm (16 in) diameter lines which functioned alternately as influent or effluent lines dependent upon the operational mode selected. The top lateral collector flange was similarly piped to the two larger headers. By proper operation of the valves at each juncture, water could selectively be directed to either system for upflow or downflow mode operation. A flow meter, which could measure flows in either direction, was included in the riser pipe of each contactor.

Backwash System--

The backwash water and drain system, previously described in association with the modifications to Filter 11-B, was also interconnected with this overhead network. Valving arrangements permitted backwash water to enter the contactor through the effluent laterals and exit through the influent laterals.

A pnuematically operated backwash rate valve was common to the four contactors. It was located on the 25.4 cm (10 in) backwash drain line. The backwash drain valve was used to maintain a backwash rate through the contactor of 407 lpm/sq m (10 gpm/sq ft).

The backwash pump was used to pump the backwash water through the contactor. The pump took its suction from the 91.4 cm (36 in) washwater line that supplied the backwash water for the B-gallery sand filters. The pump was driven by an induction type motor operating on 460 volts, 3 phase. Pump specifications are listed in Table 2.

TABLE 2. WASHWATER PUMP SPECIFICATIONS

Total Rated Head	12.2 m (40 ft)
Capacity at Rated Head	82 l/s (1300 gpm)
Minimum Operating Head	10.7 m (35 ft)
Maximum Power at Minimum Operating Head	16.3 kW (21.8 bhp)
Net Positive Suction Head (NPSH)	3.05 m (10 ft)

Influent Piping--

The connection for supplying sand filter effluent water was previously described under modifications to Filter 11B.

From this point of connection, a 40.6 cm (16 in) pipeline was run to the suction connection of the two 0.1 cu m/s (3 mgd) process pumps. The elevation of much of this line was above the hydraulic gradient of the flume, therefore, it became necessary to add a vacuum priming system.

One process pump serves the contactors with the second acting as a standby. The process pumps were driven by a horizontal, totally enclosed, 460 volt, 3 phase induction motor. The process pump specifications are shown in Table 3. The pump discharges were manifolded into a single 40.6 cm (16 in) line going through the access tunnel to the contactor building.

Effluent Piping--

The water from the effluent of the contactors flowed through a 40.6 cm (16 in) effluent line. This line was routed through the access tunnel, pump room and across the filter building where it discharged into the A-gallery effluent flume through a connection welded to the cover plate of an access manhole near Filter 13A. The long run of pipe was planned in order to introduce the contactor effluent as far downstream as practicable in order to eliminate the possibility of recirculating water, through the contactor, which had previously been through the process.

The control valves on the influent/effluent and washwater systems were pneumatically operated. Compressed air for this purpose was provided by a

TABLE 3. PROCESS PUMP SPECIFICATIONS

Total Rated Head	38.4 m (126 ft)
Capacity at Rated Head	132.5 l/s (2100 gpm)
Approximate Capacity Range	63.1-151.4 l/s (1000-2400 gpm)
Operating Head Range	29.9- 39.6 m (98-130 ft)
Maximum Power	64.9 kW (87 bhp)
Pump Rotation	Counterclockwise
NPSH	4.6 M (15 ft)

dual compressor package. The compressed air system also served the instrumentation and control requirements of the regenerator. The contactor control cabinet housed the flow and pressure indicators with recorders.

Flowmeter--Each contactor was equipped with a 15.2 cm (6 in) magnetic flowmeter capable of measuring the flow of filtered water in both directions without any moving parts in the meter coming in contact with the water. The flowmeters were designed for a maximum pressure of 1,172 KPa (170 psig). Each contactor had a two-pen indicating recorder with a chart and scale which read 0 - 0.06 cu m/s (0 - 1.5 mgd). This meter also measured the rate of backwash.

Flow indicating controller--Each contactor had a flow indicating controller to set the rate through the contactor. The flow could be controlled manually or automatically.

Pressure recorders--Each contactor had two-pen pressure recorders and indicators with a chart and scale which reads 0 - 700-KPa (0 - 100 psig). One pen recorded the pressure at the top of the contactor and the other the bottom pressure.

Instrument Air System--

The instrument air system was used for the metering and control of the contactors. The compressed air equipment consisted of two heavy duty, single-acting, two-stage, air-cooled, V-belt driven compressors, a vertical receiver and two refrigeration-type, self-contained, air dryers. The specifications for the instrument air system are shown in Table 4. The control cabinet for the system which contained indicating lights, switches, relays, solenoid valves and gauges was located immediately adjacent to the compressor.

TABLE 4. INSTRUMENT AIR SYSTEM SPECIFICATIONS

Compressor Discharge Pressure	861.9	kPa (125 psig)
Motor Speed	1,800	rpm
Power Requirement	18.6	kW (25 hp)
Receiver Test Pressure	1,034.2	kPa (150 psig)
Receiver Volume	1.1	cu m (40 cu ft)
Dryer Capacity	0.84	mm (30 scfm)
Dryer Power	0.38	kW (0.5 hp)
Receiver Dewpoint	2	°C (35°F)

REGENERATOR

Acquisition of the Regeneration Furnace

Once the extent of the Research Project was established, the required capacity for regenerating spent GAC was determined by extrapolating published[6] carbon use rates. Every known manufacturer of such equipment was contacted for information which would be helpful in writing a performance specification and to stimulate the interest of possible bidders of such equipment.

A broad-based specification was drawn calling for a 227 kg (500 lb) per hour dry regeneration capacity furnace of either the infrared or fluidized bed technology. Evaluation considerations included such items as initital capital outlay, projected operating and maintenance costs, and expected GAC loss in the process. Five bids were received, one electric infrared and four fluidized bed units. The lowest three bids were determined and a sample of GAC, previously exhausted in a USEPA pilot column study on Cincinnati water, was submitted to each of the bidders for regeneration to verify their proposed performance data. In every case the fuel requirement was increased due to the fact that the GAC loading was not as great as advance publicity lead them to believe.

Although the aggregate cost of other units over the claimed equipment life (of up to 20 years) would have been lower, Westvaco's bid of $604,000 coupled with guaranteed performance was the lowest bid for the term of the project.

Description of the Fluidized Bed Regenerator and Support Equipment

The fluidized bed regeneration process, sometimes referred to as "reactivation", is a vertical process where the GAC progresses downward through the regenerator counterflow to rising hot gases which carry off volatiles as it dries the spent GAC and pyrolyzes the adsorbate.

The regenerator vessel was 6.9 m (22.5 ft) tall and 2.1 m (7 ft) at its widest diameter (Figure 13). Typically, the outer steel shell was lined with 10 cm (4 in) of mineral wool blocks covered with a cast-in-place refractory of up to 0.36 m (14 in) thickness. From bottom to top, it was divided into three compartments which house four functional areas (Figure 13). The bottom section was the combustion chamber into which a stoichiometrically balanced stream of fuel and oxygen (air) flowed. These expanding gases of combustion provided the heat and fluidizing medium. Steam was also injected into this chamber, while it was part of the regeneration process the volumes were predicated upon the need of additional fluidizing gases. Temperatures reached approximately 1,040°C (1,900°F) in the combustion chamber which had a water-sealed pressure relief vent. The burners were of a dual fuel type which used either fuel oil or natural gas.

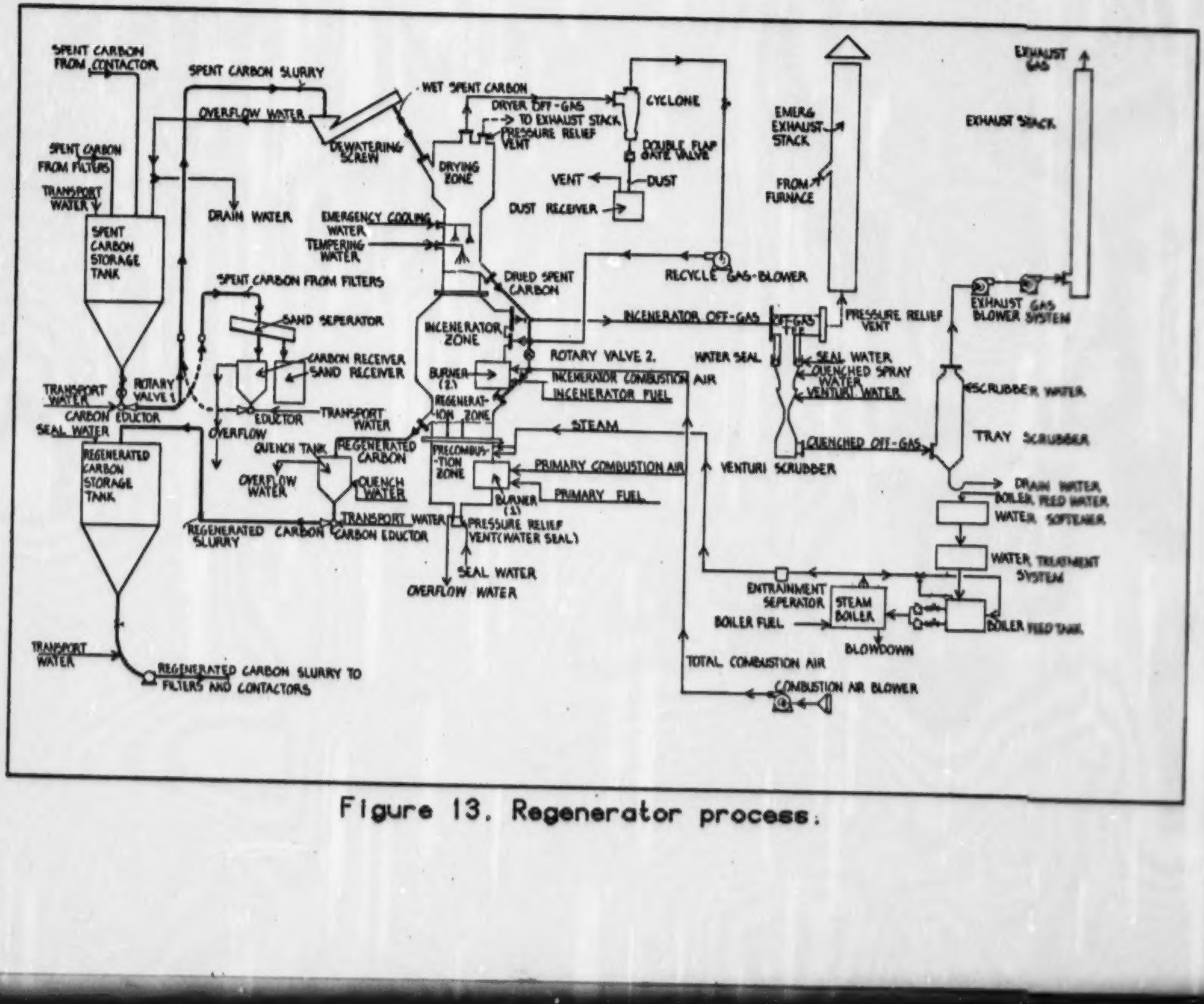

SPENT CARBON FROM CONTACTOR
SPENT CARBON SLURRY
OVERFLOW WATER
WET SPENT CARBON
DEWATERING SCREW
SPENT CARBON FROM FILTERS
TRANSPORT WATER
SPENT CARBON STORAGE TANK
DRAIN WATER
DRYER OFF-GAS
TO EXHAUST STACK
PRESSURE RELIEF VENT
DRYING ZONE
CYCLONE
DOUBLE FLAP GATE VALVE
VENT
DUST
DUST RECEIVER
EMERG EXHAUST STACK
FROM FURNACE
EXHAUST GAS
EXHAUST STACK
EMERGENCY COOLING WATER
TEMPERING WATER
DRIED SPENT CARBON
RECYCLE GAS-BLOWER
SPENT CARBON FROM FILTERS
SAND SEPERATOR
CARBON RECEIVER
SAND RECEIVER
INCENERATOR ZONE
INCENERATOR OFF-GAS
OFF-GAS TEE
PRESSURE RELIEF VENT
EXHAUST GAS BLOWER SYSTEM
ROTARY VALVE 2.
WATER SEAL
SEAL WATER
QUENCHED SPRAY WATER
VENTURI WATER
TRANSPORT WATER
ROTARY VALVE 1
CARBON EDUCTOR
SEAL WATER
BURNER (2)
INCENERATOR COMBUSTION AIR
INCENERATOR FUEL
SCRUBBER WATER
EDUCTOR
TRANSPORT WATER
OVERFLOW
REGENERATION ZONE
STEAM
TRAY SCRUBBER
QUENCHED OFF-GAS
QUENCH TANK
REGENERATED CARBON
REGENERATED CARBON STORAGE TANK
PRECOMBUSTION ZONE
PRIMARY COMBUSTION AIR
VENTURI SCRUBBER
OVERFLOW WATER
QUENCH WATER
BURNER (2)
PRIMARY FUEL
DRAIN WATER
BOILER FEED WATER
WATER SOFTENER
TRANSPORT WATER
REGENERATED CARBON SLURRY
CARBON EDUCTOR
PRESSURE RELIEF VENT (WATER SEAL)
SEAL WATER
OVERFLOW WATER
WATER TREATMENT SYSTEM
ENTRAINMENT SEPERATOR
STEAM BOILER
BOILER FUEL
BOILER FEED TANK
BLOWDOWN
TRANSPORT WATER
REGENERATED CARBON SLURRY TO FILTERS AND CONTACTORS
TOTAL COMBUSTION AIR
COMBUSTION AIR BLOWER

Figure 13. Regenerator process.

The regeneration zone was separated from the combustion chamber by a stainless steel diaphragm fitted with a number of nozzles which distributed the gases uniformly over the cross section of the furnace. It also supported the GAC when at rest. A series of weir plates rested upon the diaphragm plate to assure sufficient residence time for the GAC in process. The upper part of this chamber was the incineration zone. Additional air and fuel were injected by the secondary burner to incinerate organics from both the regenerator and dryer zones. Temperatures across this chamber averaged 816°C (1,500°F).

The furnace off-gas was conducted from the regeneration/incineration chamber through a breaching, a venturi scrubber, a tray scrubber and discharged to the atmosphere by a stack through the roof. The breaching was equipped with a safety blow-out panel which would release excessive pressures through a relief stack.

The third chamber, smallest in volume, was the dryer which was separated from the regenerator/incinerator by 316L stainless steel plate perforated with a uniform pattern of holes to distribute the gas flow to attain uniform fluidization of the GAC bed above it. The gas flow through this chamber was induced by the suction of a fan, creating a negative pressure within the chamber. The gas flow went through a cyclone separator which dropped out much of the suspended particulates (GAC fines). The blower then discharged into the incinerator zone where the entrained volatiles, which were driven off the GAC in the drying process, and the remaining particulate matter were incinerated. The temperature within the dryer was approximately 150°C (300°F) and was controlled with cooling water sprays located above the GAC bed. The dryer chamber also had emergency water sprays and a blow-out panel type pressure relief vent connected to the relief stack.

The furnace contract also included two cylindrically-walled, conically-bottomed tanks, each had a capacity of 23.9 cu m (855 cu ft), fabricated of 316L stainless steel, one for receiving and holding spent GAC prior to regeneration (ST-1) and the other to receive and hold regenerated GAC (ST-2) until it could be returned to the filter or contactor from which it came (Figure 11). Spent GAC was discharged from ST-1 through a variable speed rotary valve (RV-1), the rotational speed of which was controlled by the operator. This determined the rate of feed to the furnace. The GAC was moved from RV-1 by an eductor to either the sand separator or to the dewatering screw.

A sand separator, which was an application of a standard piece of placer mining equipment, was utilized only when GAC from a filter was being regenerated. It was a vibrating table designed to separate material through their difference in specific gravity. The sand was discharged to a portable dump hopper for disposal and the GAC was discharged into a stainless steel vessel which was fitted with an eductor which transported the GAC to the dewatering screw.

The dewatering screw, which was an inclined screw conveyor, discharged wet GAC directly into the dryer section of the regenerator. The GAC traversed across the dryer plate and through a side pipe. It passed through a rotary valve (RV-2) and reentered the furnace at the regeneration zone. The rotary valve served to isolate the two pressure zones within the process. The GAC flowed across the regenerator bed to an outlet port and discharge chute to the quench tank. The discharge chute was submerged to prevent entry of excess oxygen into the process. An eductor at the bottom of the quench tank transported the GAC to ST-2. An A-S-H rubber-lined slurry pump was used to transfer the regenerated GAC to a filter or a contactor.

Most of the equipment to support direct operations of the regenerator were a part of Westvaco's contract. Foremost of these was a Bristol microprocessor/controller and a recording unit. This was housed in a controlled environment room within the main building. The instrumentation and control systems were designed to require only the minimum of attention by the operator. However, it was seldom that all of the automated systems were functional and the successful operation relied heavily upon the skills of the CWW operating and maintenance personnel.

A three-stage turbo blower supplied the combustion air for both the regenerator and incinerator burners. The recycled gas blower which handled the dryer off-gas and reinjected it into the incinerator section, also provided the gas movement required to fluidize the dryer bed. Particulate matter in the recycled gases were removed by a cyclone separator. Two blowers in series handled the furnace off-gases which also passed through a venturi and a tray-type scrubber. All parts of the various gas handling apparatus that were in contact with the gas stream were fabricated of 316L stainless steel.

There was also a steam generator to provide the steam required in the process. It, like the furnace, may be fired by either gas or fuel oil.

Appurtenant to the regenerator were the fuel oil day tank and two 0.2 l/s (3.2 gpm) centrifugal pumps which supplied contactor effluent water for steam generation, quenching and transporting regenerated GAC.

GAC Treated Process Water Piping and Pumps

Two 12.6 l/s (200 gpm) pumps (EP-1 & EP-2) provided contactor effluent for the steam generator, tempering water, quenching water, and transporting regenerated GAC, thereby reducing exposure to organic laden water.

The suction was initially tapped into the 40 cm (16 in) contactor effluent line just before it left the contactor building. With all four contactors in service the pumps became air-bound and lost their prime. The suction connection was moved to the drop leg as the 40 cm (16 in) line entered the tunnel area making a trap configuration, assuring a full line. Apparently, turbulance entrained sufficient air to cause the pumps to become air bound.

Reliable service was achieved only by relocating the pumps to the floor of the stairwell which connects the building to the access tunnel (Figure 11).

The 40 cm (16 in) contactor effluent pipe was tapped adjacent to the pumps, providing a positive suction head with only two contactors in service. A 7.6 cm (3 in) discharge header was routed to the north end of the building along the east wall.

GAC Transport Piping

A 7.6 cm (3 in) carbon-in pipe line was connected to the top of each contactor tank from a central header which terminated near the center of the building. Similarly, a 7.6 cm (3 in) carbon-out line ran from the bottom of each contactor to a header which terminated at a point approximately 30 cm (1 ft) below the carbon-in line. A third line which began outside the building provided a connection for unloading or loading GAC trucks and terminated on a 90 degree alignment to the carbon-in and carbon-out lines and at the same elevation [approximately 3.7 m (12 ft)] above the floor. A quick-disconnect hose permitted various modes of interconnection between these and the GAC transport piping provided by others (Figures 4 and 12).

The furnace installation included GAC transport piping that originated at a point on the extended centerline and 1.8 m (6 ft) from the terminous of the carbon-out line described above. This line discharged vertically downward into the top of the spent GAC tank (ST-1).

From the bottom of ST-1, the GAC, motivated by water pressure through an eductor, was selectively conducted to the dewatering screw which fed the furnace or to a sand separator which discharged GAC into a receiving tank equipped with a second eductor which was then connected to the dewatering screw feed line.

GAC coming out of the furnace dropped into a quench tank (QT-1). An eductor at the bottom of QT-1 propelled the GAC through a pipe which discharged at the top of the regenerated GAC storage tank (ST-2). A slurry pump at the bottom of ST-2 moved the regenerated GAC through a transport pipe which terminated facing the carbon-in line with a 1.8 m (6 ft) gap between them where the quick-disconnect hose, described above, could direct the product to a selected contactor or filter.

Two 10.2 cm (4 in) GAC transport lines traversed the Filter Building from the area of the filters in A-gallery, to the GAC building. One line terminated at the top of ST-1, bringing GAC from the filters, the other terminated in the area of the other open ends of GAC piping in the center of the building. By use of a flexible hose connection, a number of combinations could be selected including: truck to contactor, truck to filter, filter to truck, contactor to filter, filter to contactor, regenerator (ST-2) to contactor, regenerator to filter, contactor to regenerator (ST-1), truck to regenerator (ST-1), or regenerator (ST-2) to truck.

These lines were assembled with Victaulic connections to permit ease of rearrangement within the filter area and removal of sections for clean out in the event of plugging. All bends in the GAC transport system were of a long radius design in order to reduce frictional loss of GAC.

CONTACTOR/REGENERATOR BUILDING

Design work covering all aspects of the project began in early September, 1977. In the interest of establishing the earliest possible progress, and in hopes of having the concrete work done before severe winter weather set in, a contract was let for the construction of the building foundation, one half of the floor slab and a utility tunnel connecting the proposed building to the existing Filter Plant. A standard modular building was selected which could house the contactor tanks, whose size and number were established, and could accomodate either an infrared electrical furnace (horizontal process) or a fluidized bed gas fired furnace (vertical process) which would ultimately be situated on the other half of the floor slab. The tunnel was actually an adaptation of a large prefabricated culvert pipe. A severe winter and late delivery of the tunnel line delayed completion of this phase until August, 1978.

LABORATORY

Establishment of an Organics Laboratory

One condition imposed by the USEPA before they would approve the grant was that CWW must establish, at their own cost, a laboratory capable of conducting organic analyses of the type to be involved during the research project. The existing laboratory was overtaxed with routine analytical work to the point where a capital expansion project was underway, but it would not be available in time to meet the schedule of the proposed program. A lecture room (5.8 m x 10.1 m, 19 ft x 33 ft) was converted to an organics laboratory.

Work on the conversion began in the spring of 1977. Progress of the work was dependent upon delivery of the larger items of equipment which included a fume hood, an ultra-high temperature oven (muffle furnace), a Varian 3700 gas chromatograph (GC) with a Hall detector, a Linear recorder and a Tekmar LSC-1 concentrator. At the same time, A Dohrman DC-50 TOC analyzer, existing in the general laboratory, was being retrofitted to the DC-54 configuration with an ultra-low level analyzer.

It immediately became apparent that the air conditioning system designed for the lecture room would not be adequate for the laboratory conversion due to the heat-producing equipment that would be in use. As a temporary measure, the CWW welding shop designed, fabricated, and installed additional fresh air ducts and vents to the existing system to maximize air circulation to the room. In addition, one of the laboratory windows was modified and a 10.1 MJ/hr (9,600 BTU/hr) window unit was installed.

In order to simulate the same conditions that the finished water in the distribution system would encounter, three ambient temperature units were designed and constructed. These consisted of three 18.9 l (20 quart) coolers fitted with sample bottle racks, an air-gapped water supply and a drain. A steady stream of water flowing through these units would maintain the samples at approximately the same temperature as that of water in the distribution system. An incubator that was in storage was reconditioned and placed in service.

Storage for liquid nitrogen, necessary for subambient operation of one of the Varian 3700 GC's was provided in the front cross gallery of the filter building. An access hole was cored through an adjoining wall into the laboratory and an insulated pipe was installed from the storage tank through the wall to the instrument.

Table 5 lists the major items of work and equipment associated with the pre-grant commitment.

New Laboratory Addition

After passage of the Safe Drinking Water Act[7] the CWW administration determined it would be necessary to modernize and expand the existing facilities to accommodate increased staff and new instrumentation necessitated by the new regulations. Consulting engineers were commissioned to design the laboratory addition. The new laboratory, not funded by the project grant, became available as the grant study progressed and was utilized to relieve

TABLE 5. PRE-GRANT COSTS OF ESTABLISHING ORGANICS LABORATORY

Item	Material	Labor	Total
Electrical Services	$ 1,500	$ 9,400	$10,900
Incubator	-	200	200
Cold Water Piping	20	200	220
Hot Water Piping	20	200	220
Natural Gas Piping	30	250	280
Drains and Cup Sinks	80	300	380
Distilled Water Piping	50	150	200
Ambient Temperature Units	120	900	1,020
Fume Hood	4,500	4,000	8,500
Ultra-high Temperature Oven	2,230	80	2,310
Vacuum Pumps and Piping	400	240	640
Air Compressors and Piping	800	480	1,280
Gas Tank Rack and Piping	300	550	850
Temporary Air Conditioning Provisions	100	330	430
Permanent Air Conditioning	2,000	5,780	7,780
Liquid Nitrogen Facilities	30	100	130
Initial Cleaning and Painting	300	1,000	1,300
Miscellaneous Items of Work	500	1,500	2,000
Table Tops and Consoles	900	3,100	4,000
Gas Chromatograph	16,600	600	17,200
Ultra-low Level TOC Module	7,590	80	7,670
	$38,070	$29,440	$67,510

overcrowded conditions in the existing laboratory. A gas chromatograph/mass spectrometer (GC/MS), which was funded by and utilized in the final phase of the study, was housed in the new laboratory. Use of this equipment was delayed until the laboratory was completed and the environmental control system balanced and regulated.

The laboratory addition provided an additional 427.3 sq m (4,600 sq ft) of laboratory and office space. A new heating, air conditioning and ventilating system for both the new and existing laboratory space was provided in the construction contracts.

The new laboratory provided space for radiological equipment, GC/MS, atomic absorption; expanded physical, chemical, and microbiological testing, GAC analyses, extractions, and other related support equipment. The remodeled organics laboratory provides the CWW with an excellent facility for water quality and research analyses. This facility was dedicated on May 5, 1980.

Laboratory Equipment Acquisition and Installation

In the grant application, CWW committed itself to procure and/or install certain facilities and equipment in advance of the grant period and outside of the grant funding. Accordingly, the CWW requisitioned selected pieces of analytical equipment and established an organics laboratory as previously discussed.

Table 6 identifies the various vital statistics associated with major pieces of lab equipment acquired or installed. There are always considerable unanticipated delays associated with the acquisition and installation of laboratory equipment. CWW's experience was no exception. Such being the case, only those equipment acquisitions, installations or shakedown problems that significantly affected our ability to meet grant objectives are highlighted in footnotes to Table 6.

DATA MANAGEMENT

During grant planning, costs and problems associated with the recording, sorting, reporting and evaluation of data were under-estimated. In sheer numbers alone, close to 150,000 pieces of data have been computerized. Originally grant data were recorded in the same fashion as was done with routine laboratory data; that is, in log books, diaries and on a few specially prepared forms. Reporting of these data in required quarterly reports was initially done by photocopying handwritten forms, then through typewritten versions of the handwritten forms.

Although CWW uses computer services provided by the Regional Computer Center (a City and County sponsored computer center), the availability of needed services was extremely difficult to obtain and development time was usually long. The inadequacy of this system quickly became apparent. In order to evaluate grant operations, graphs would be needed and doing these

TABLE 6. LABORATORY EQUIPMENT INVENTORY

Item Description	Manufacturer	Model #	Req. Date	P.O. Date	Equip. Rec'd. Date	Purchase Price	Install. Cost	Total Acq. Cost
GC/ Electron Capture	Varian	3700	03/31/77	04/21/77	07/05/77	$ 9,465	$ 403	$9,868
EC/ Electrolytic Cond. Detector	Tracor Hall	T700	03/31/77	04/21/77	05/10/77	3,514	100	3,614
GC Liquid Sample Concentrator	Tekmar	LSC-1	03/31/77	04/22/77	06/16/77	3,619	100	3,719
GC Dual Pen Recorder	Linear	385	03/31/77	04/22/77	06/16/77	b	b	b
Fume Hood	Hamilton Ind.	540H947	05/31/77	07/15/77	10/06/77	4,455	3,957	8,412
Ultra-Low-Level TOC Analyzer Module	Dohrman	PR-1	03/31/77	05/19/77	a	7,591	82	7,673
Muffle Furnace	Blue M	BFD-20F-3	09/14/77	09/30/77	11/14/77	2,232	80	2,312
Analytical Balance	Sartorius	2434	10/25/77	12/05/77	12/20/77	1,440	-	1,440
GC/FID	Perkin-Elmer[c]	Sigma 1	a	12/01/77	06/05/78	16,937	a	a
GC Microprocessor	Perkin-Elmer[c]	Sigma 10	a	12/01/77	03/13/78	d	d	d
GC/MS Cool Water Recirculator	Neslab Instrumts.	CFT-25	03/19/79	04/30/79	05/29/79	815	-	815
Water Bath (Ambient)	CWW Fabric.	-	a	a	a	128	1,402[e]	1,530
Safety Refrigerator	Labline	355-10	01/05/78	02/13/78	03/07/78	593	-	593
GC/FID	Varian	3740	01/16/79	08/20/79	01/30/80	8,158	a	a
GC/Electronic Integrator	Spectra Physics	SP4100	01/16/79	08/01/79	09/27/79	6,550	a	a
GC/FID Capillary Column	Varian	3700	c	c	02/01/80	c	687	c
GC/MS	Finnigan	OWA-20	11/17/78	02/15/79	07/20/79	85,755	a	a
GC/Misc. Accessories	Varian	NA	07/12/79	10/11/79	01/02/80	4,230	a	a
GC Integrator	Spectra Physics	SP4100	c	c	02/01/80	c	-	c
Mixer Mill	Spex	8000	a	a	08/29/80	1,141	-	1,141

[a] Not available.

[b] Included in cost of Varian GC above.

[c] Due to numerous problems with the Perkin-Elmer instrument and detector, this unit was eventually traded evenly to ORSANCO for the Varian 3700 GC and integrator.

[d] Purchased by ORSANCO for CWW use under the Early Warning Organics Detection System (EWODS), used also for grant work.

[e] In order to store water samples at ambient water temperatures, CWW fabricated water bath equipment from picnic coolers and tubing. Considerable plumbing was necessary to make unit operational.

graphs manually was cumbersome, costly and did not produce the graphs in sufficient quantity on a timely basis. Even output reports showing related data on the same listing were not possible.

Considerable difficulty would be encountered later in the project. For that reason other possibilities were considered. A local computer center, Southwestern Ohio Regional Computer Center (SWORCC), in conjunction with the USEPA, was exploring the feasibility of using graphic computer software. Later, under a contract with another local firm, computing capabilities were developed at the University of Michigan. By acquiring a graphics terminal, the CWW was able to access its data (stored at the University of Michigan) and produce the outputs required. Table 7 lists the equipment purchased as part of the cooperative agreement.

TABLE 7. GRAPHICS EQUIPMENT

Equipment	Tektronix Model #	Cost
Graphics Computer	4051	$ 9,892
Printer	4642	2,609
Plotter	4662	4,621
Accessories	--	703
		$17,825

SECTION 5

METHODS AND OPERATING PROCEDURES

PHYSICAL PLANT

Operational parameters were standardized to establish, as near as possible, constant or reproducible conditions to generate valid data. These parameters were determined by experimentation and/or equipment manufacturers' recommendations. Tables 8 and 9 contain actual operating conditions for the full and pilot scale systems. Nominal operating parameters are described in the following subsections.

GAC Filters

The most significant deviation from standard plant operations was the reduction of the backwash rate from 5.3 l/min/sq m (15 gpm/sq ft) to 2.8 l/min/sq m (8 gpm/sq ft) to reduce GAC losses. During experimentation, backwash rates that approached standard plant operation resulted in observable GAC losses. These and other GAC filter operating parameters appear in Table 10.

Pilot Columns

Pilot GAC Filters--

During Phase 2, two 7.6 cm (3 in) pilot GAC filters were used, one contained virgin GAC, the other contained regenerated GAC. During Phase 3, only one column was in service. Initially the column contained virgin GAC and on subsequent runs regenerated GAC. This column always matched GAC Filter 15A. Operating parameters for both phases are shown in Table 11.

Pilot GAC Contactors--

During Phase 2, two sets of 10.2 cm (4 in) diameter pilot contactors were on line, one contained lignite GAC, the other contained bituminous GAC. During Phase 3, one bituminous GAC pilot contactor was on line. The operating parameters for the two pilot-scale units are contained in Table 12.

On the bituminous pilot GAC contactor, the second, third and forth tubes in the series had limited freeboard which required reduction of backwash rates in order to reduce bed expansion. Except for the fact that the lignite pilot contactors had longer tubes with sufficient freeboard to

TABLE 8. ACTUAL OPERATING CONDITIONS FOR FULL-SCALE GAC SYSTEMS

GAC System[a]	Phase-Run[a]	GAC Depth[b] m	GAC Weight kg	Water Thruput[c] mil l	Length of Run[d] days	Avg EBCT min	Avg Hyd Ldg lpm/sq m
15AE	3-0	0.76	43,185	3,407	180	7.56	101
15AE	3-1	0.75	44,500	852	45	7.43	101
15AE	3-2	0.75	47,719	814	43	7.40	101
15AE	3-3	0.77	47,525	1,221	64	7.60	101
15AE	3-4	0.74	47,689	3,709	196	7.30	101
19AE	1-0	0.46	26,655	13,854	732	4.53	101
21AE	1-0	0.76	44,418	14,725	778	7.56	101
21AE	3-1	0.77	47,715	814	43	7.63	101
21AE	3-2	0.77	48,939	1,779	94	7.66	101
21AE	3-3	0.74	49,133	3,558	188	7.31	101
23AE	1-0	0.76	50,173	16,390	866	7.56	101
AE	3-0	4.61	19,936	1,210	317	15.41	300
AE	3-1	4.55	19,659	393	103	15.20	300
BE	3-0	4.58	19,922	870	228	15.28	300
BBE	3-0	4.55	19,659	427	112	15.20	300
BBE	3-1	4.60	19,880	504	132	15.37	300
CE	3-0	4.59	19,811	855	224	15.32	300
CE	3-1	4.60	19,880	355	93	15.37	300
DE	3-0	4.59	19,825	778	204	15.32	300
DE	3-1	4.57	19,756	401	105	15.26	300
DE	3-2	4.61	19,936	485	127	15.42	300

[a] For description of GAC System and Phase-Run refer to Appendix A.

[b] GAC depth in contactors was measured from centerline of bottom laterals.

[c] Based on flow controller settings of 3.8 mil lpd (1 mgd)for contactors and 18.9 mil lpd (5 mgd) for GAC filters.

[d] Actual run time, not including the time the units were out of service for backwashing, etc.

TABLE 9. ACTUAL OPERATING CONDITIONS FOR GAC PILOT COLUMNS

GAC System[a]	Phase-Run[a]	GAC Depth m	GAC Weight kg	Water Thruput[b] kl	Length of Run[c] days	Avg EBCT min	Avg Hyd.Ldg. lpm/sq m
RV3	2-1	0.76	1.45	66.5	135	10.18	73.9
RV3	2-2	0.78	1.46	59.8	128	10.87	71.5
RV3	3-1	0.76	1.55	30.2	46	7.55	101.0
RV3	3-2	0.76	1.78	27.4	43	7.83	97.6
RV3	3-3	0.76	1.73	41.5	64	7.69	99.3
RV5	2-1	0.76	1.65	67.3	135	10.22	74.8
RV5	2-2	0.78	1.51	62.8	128	10.37	75.0
RV5	3-0	0.76	1.41	116.3	180	7.59	100.6
PFA5	1-0	4.57	18.09	864.0	237	14.70	311.9
PFA5	3-0	4.57	18.24	758.3	210	14.80	309.1
PFA5	3-1	4.57	18.09	356.8	106	15.80	289.5
PFA5	3-2	4.57	16.92	380.3	128	16.40	279.0
PFA9	1-0	4.57	14.43	889.3	237	14.30	321.2

[a] For description of GAC System and Phase-Run refer to Appendix A.

[b] Based on meter or counter readings.

[c] Actual run time, not including the time units were out of service for backwashing, etc.

TABLE 10. NOMINAL OPERATIONAL PARAMETERS FOR GAC FILTERS

Hydraulic Loading Rate	102	l/min/sq m (2.5 gpm/sq ft)
Contact Time (Empty Bed)	7.48	min
Backwash Rate (Max.)	327	l/min/sq m (8 gpm/sq ft)
Frequency of Backwash	1.8	m (6 ft) head loss
Backwash Time	12	min/wash
Backwash Water Used	378,500	l/wash (100,000 gal/wash)

TABLE 11. NOMINAL OPERATIONAL PARAMETERS FOR PILOT GAC FILTERS

Hydraulic Loading Rate	102	l/min.sq m (2.5 gpm/sq ft)
Contact Time (Empty Bed)	7.6	min
Backwash Rates	745	l/min/sq m (18.3 gpm/sq ft)
Frequency of Backwash	3	times/wk[a]
Backwash Time	20	min/wash
Backwash Water Used	75.7	l/wash (20 gal/wash)
Static Head Above Carbon Bed	2.5	m (9 ft)

[a] Head loss not measured.

TABLE 12. NOMINAL OPERATIONAL PARAMETERS FOR PILOT CONTACTORS

Hydraulic Loading Rate	302 l/min/sq m (7.4 mgd/sq ft)
Contact Time, Empty Bed	15 min
Backwash Rates, Bituminous	
Tube 1	409 l/min/sq m (10 gpm/sq ft)
Tube 2	192 l/min/sq m (4.7 gpm/sq ft)
Tube 3	192 l/min/sq m (4.7 gpm/sq ft)
Tube 4	192 l/min/sq m (4.7 gpm/sq ft)
Backwash Rates, Lignite	
Tube 1	409 l/min/sq m (10 gpm/sq ft)
Tube 2	409 l/min/sq m (10 gpm/sq/ft)
Tube 3	409 l/min/sq m (10 gpm/sq ft)
Tube 4	409 l/min/sq m (10 gpm/sq ft)
Backwash Water, 10 min	189 l (50 gal)
Backwash Water, 20 min	378 l (100 gal)
Backwash Criterion[a]	138 kPa (20 psig)

[a] Not required during some runs of Phase 3, see text for modifications.

accomodate full backwash rates on all four tubes, all operating parameters for the two pilot contactor systems were the same.

Initially in Phase 2, an arbitrary 172 kPa (25 psig) head loss across a pilot contactor was selected as the criterion for backwashing. On the first attempt to backwash a pilot contactor, it became apparent that the selected head loss was too great. The GAC had been compressed into a plug which was difficult to break up. The criterion was revised to 138 kPa (20 psig) back pressure, which proved to be acceptable. Eventually the gauge ports became clogged with GAC and subsequently the tubes were backwashed when throughput diminished.

The contactors had an effective depth of 4.6 cm (15 ft) from the centerline of the bottom laterals. Below the bottom laterals was an additional 3.8 cu m (136 cu ft) volume of GAC (Figure 12).

Contactors

The backwash parameter of 138 kPa (20 psig) pressure drop across the bed was never attained on the contactors during Phase 3 through normal operation. The one occasion which required backwashing was due to air binding following a process pump failure. All contactors were backwashed prior to being put into service in order to purge fines which might clog the lateral screens or cause turbidity problems. Each contactor was backwashed again prior to removing the GAC for regeneration. The purpose of the final wash was to loosen the bed to facilitate hydraulic movement of the GAC and to relax and level the bed for accurate measurements for determing GAC losses. A turbidimeter was installed on the combined contactor effluent line.

A standardized backwash procedure, designed to obtain a reproducible bed volume for measurement purposes, was recommended by the GAC supplier. This method, described below, was utilized for all backwashing operations.

Backwash was started at a rate of 122 l/min/sq m (3 gpm/sq ft) then gradually increased to 407 l/min/sq m (10 gpm/sq ft) and held there for thirty minutes. The rate was then gradually reduced to zero and the bed permitted to settle for five minutes. Backwashing was again started and gradually reduced to zero and the bed permitted to settle for five minutes. Backwashing was again started and gradually increased to 407 l/min/sq m (10/gpm/sq ft), held for fifteen minutes and then gradually reduced to zero. Backwashing and other nominal operating parameters are shown on Table 13.

Regenerator

The regenerator was controlled by a Bristol UCS 3000 microprocessor. Nine pneumatic control loops were provided for the process:

1. regenerator bed temperature,
2. air fuel ratio,
3. steam flow (total gas flow to combustion chamber),
4. incinerator gas temperature,
5. incinerator off-gas oxygen content,
6. gas flow rate through the dryer,
7. dryer bed temperature,
8. dryer pressure,
9. scrubber's venturi pressure drop.

Start-up--

The microprocessor was loaded with one of two diskette programs, natural gas or fuel oil. The dryer was charged with 63.5 kg (140 lbs) of virgin GAC. Prior to igniting the primary burner, the furnace was purged with air for two minutes. On completion of the purge cycle, the pilot light was ignited. The fuel blocking valves were opened to light the primary burner (Figure 13). The temperature in the regenerator bed section was raised to

TABLE 13. NOMINAL OPERATIONAL PARAMETERS FOR CONTACTORS

Hydraulic Loading Rate	302	l/min/sq m (7.4 gpm/sq ft or 1 mgd)
Contact Time (Empty Bed)	15.3	min
Backwash rates (Max)	409	l/min/sq m (10 gpm/sq ft)
Frequency of Backwash	138	kPa (20 psig) head loss
Backwash Time	45	min
Backwash water per wash	143,100	l (37,800 gal)

260°C (500°F) at which time steam was admitted to the combustion chamber. When the temperature in the incinerator section reached 370°C (700°F), the incinerator pilot was lit, the fuel blocking valves were opened and the incinerator burner was lit.

After the regenerator bed section reached 815°C (1,500°F) and enough heat was transferred from the incinerator section to the dryer section to require 2.6 to 3.4 l/min (0.7 to 0.9 gpm) water flow through the dryer spray cooling water meter to maintain 150°C (300°F) in the dryer bed, GAC feed was started at approximately 63.5 kg (140 lbs)/hr rate. The GAC feed rate was increased, in increments of 77 kg (170 lbs)/hr at intervals of thirty minutes. As the GAC feed rate was increased the temperature was increased in the incinerator section to maintain 0.76 to 1.5 l/min (0.2 to 0.4 gpm) cooling water flow to the dryer to maintain proper dryer bed temperature. Approximately four hours elapsed from start-up to full-feed rate.

The degree of regeneration was determined by apparent density and iodine number analyses which were performed on three samples daily. Apparent density was the primary controlling factor and dictated regenerator bed temperature adjustments, in 5.5°C (10°F) increments, as needed. Furnace operations were fine tuned using iodine number results. The system temperatures were allowed to stablize after each incremental temperature increase with the maximum temperature of 1,090°C (2,000°F) in the combustion chamber. Another factor limiting the amount of spent GAC that could be fed to the regenerator was the dryer temperature. If the spent GAC contained excessive moisture, the feed rate was reduced to maintain 150°C (300°F) in the dryer. See Table 14 for operational parameters.

All control loops of the regenerator were designed to operate in the automatic mode. Manual control of all control loops, except primary air and steam, was possible when the need arose.

At times, gas flow to the dryer was restricted due to the holes in the dryer plate becoming clogged. The holes were cleared by drilling them out with a 3.2 mm (1/8 in) drill bit. At times the seal between the incinerator and dryer section leaked, the hot gases bypassing the dryer plate, thereby reducing bed fluidization. When this condition progressed to the point where the control valve in the dryer off-gas line reached 100% open, the gasket between the incinerator and dryer section had to be replaced. When the seal between the combustion chamber and regenerator bed section deteriorated, the hot gas flow bypassed the regenerator plate necessitating replacement of this gasket.

When a GAC filter was being regenerated, sand and gravel entered the dryer and regenerator sections due to the inefficiency of the sand separator. The sand and gravel migrated to the bottom of the fluidized bed thus insulating the GAC in the upper part of the bed from the fluidizing gas flow. After approximately 120 hours, the regenerator had to be shut down and the sand and gravel removed from the dryer and regenerator plates.

TABLE 14. NOMINAL GAC REGENERATOR PARAMETERS

Feed Rate (Spent GAC)	265			kg (585 lbs)/hr
Regenerated GAC Output	231			kg (510 lbs)/hr
Regenerator Distributor Plate DP[a]	10.1	to	20.3	cm (4 to 8 in) H_2O
Combustion Chamber Pressure	30.5	to	48.3	cm (12 to 19 in) H_2O
Regenerator Fluid Bed DP	6.4	to	8.9	cm (2.5 to 3.5 in) H_2O
Incinerator Pressure	7.6	to	17.8	cm (3 to 7 in) H_2O
Dryer Plate DP	5.1	to	15.2	cm (2 to 6 in) H_2O
Gas Flow Rate	14.2	to	16.1	cu m/min (500 to 570 SCFM)
Dryer Bed DP	7.6	to	15.2	cm (3.0 to 6.0 in) H_2O
Dryer Pressure	-2.5	to	-7.6	cm (-1.0 to -3.0 in) H_2O
Dryer Off-Gas Annubar	3.3	to	4.6	cm (1.3 to 1.8 in) H_2O
DP (Off-Gas Flow Rate)	18.4	to	20.4	cu m/min (650 to 720 SCFM)
Venturi Scrubber DP	5.1	to	30.5	cm (2 to 12 in) H_2O
Tray Scrubber DP	10.1	to	22.9	cm (4 to 9) H_2O
Combustion Chamber Temperature	982	to	1,093	°C (1800 to 2000°F)
Regenerator Bed Temperature (at Discharge Port)	788	to	843	°C (1450 to 1500°F)
Incinerator Temperature	677	to	871	°C (1250 to 1600°F)
Dryer Bed Temperature	149	to	163	°C (300 to 325°F)
Combustion Chamber Gas Analysis	0.4%	to	0.0%	excess O_2
Incinerator Gas Analysis	4.0%	to	2.0%	excess O_2
Regenerator Fuel Oil Flow Rate			25.7	l/hr (6.8 GPH) + 10%
Exhaust Gas Annubar DP	0.4	to	0.8	cm (0.15 to 0.3 in) H_2O
(Exhaust Gas Flow Rate)	12.7	to	17.0	cu m/min (450 to 600 SCFM)
Regenerator Natural Gas Flow Rate	0.4	to	0.5	cu m/min (14 to 18 SCFM)
Regenerator Combustion Air[b]	0.4	to	0.5	cu m/min (140 to 180 SCFM)
Steam	136	to	181	kg (300 to 400 lb)/hr
Regenerator Total Fluidizing Gas Flow Rate[c]	7.1	to	8.5	cu m/min (250 to 300 SCFM)
Incinerator Natural Gas Flow Rate	0	to	0.5	cu m/min (0 to 16 SCFM)
Incinerator Combustion Air	6.8	to	9.9	cu m/min (240 to 350 SCFM)
Incinerator "Flame" Temperator	816	to	982	°C (1500 to 1800°F)
Dryer Off-Gas Temperature	121	to	177	°C (250 to 350°F)
Off-Gas Temperature				
Venturi Scrubber Inlet	316	to	538	°C (600 to 100°F)
Venturi Scrubber Outlet	93	to	204	°C (200 to 400°F)
Tray Scrubber Outlet	43	to	82	°C (110 to 180°F)
Regenerator Combustion Air/Fuel Ratio				
Natural Gas	8.8	to	9.1	
Fuel Oil	8.6	to	9.1	
Incinerator Fuel Oil	13.2	to	26.5	l/hr (3.5 to 7.0 gpm)

[a] Differential pressure.

[b] Set point is determined by fuel-air ratio and oxygen trim controllers in software.

[c] Set point in determined by total fluidizing gas flow controller in software.

Shut Down--

Prior to shutting the regenerator down, the GAC bed remaining in the regenerator section was gasified. This was accomplished by extinguishing the incinerator burner, raising the temperature in the regenerator bed section to 870°C (1,600°F) and increasing the oxygen to the combustion chamber. Under these conditions the GAC bed was gasified (burned away).

After the bed was gasified, the temperature in the regenerator section was lowered gradually to 580°C (1,000°F) at which time the primary burner was extinguished. When the temperature in the regenerator bed section reached 260°C (500°F), the GAC remaining in the dryer was removed by vacuuming.

Purging--

If the regenerator was shut down and restarted at temperatures above 260°C (500°F) (hot restart), the regenerator was purged with steam. At temperatures below 260°C (500°F) air was used for purging.

GAC Loss Measurements--

Losses were generally measured "bed-to-bed," that is, a measurement was taken before GAC was removed for regeneration and after the regenerated GAC was placed back in the bed. In addition, attempts were made to measure losses due to transporting the GAC and those that occurred only within the furnace battery limits. The furnace battery limits included everything between the spent carbon storage tank and the regenerated carbon storage tank (Figure 13). All loss measurements were based on volume. The procedures for the various measurement techniques appear below.

GAC filter measurement--

1. Close the filter drain.

2. Open the backwash supply valve slowly in order to level the GAC evenly over the filter area without discharging GAC into the washwater troughs.

3. Backwash the filter, described previously.

4. After the backwashing, drain the filter until the water level is below the GAC surface.

5. Place a straight edge across the top of the washwater trough and measure the distance from the straight edge to the GAC surface. Take three measurements, one on each side and one in the middle of each of the eight filter openings for a total of 24 measurements.

Contactor measurement--

1. Backwash contactor.

2. Stop the backwash pump and allow the water in the contactor to drain below the top laterals. Release vacuum.

3. After vacuum is released from the contactor, open the observation port.

4. Lower the tape measure into the port until the attached plate rests on the GAC surface. Measure the distance the plate dropped, using the top of the port flange for a reference point.

5. Measure at 4 points around the circumference of the port and take one measurement at the center of the port. Average the measurements.

6. Subtract this measurement taken from 7.1 m (23.2 ft). This represents the number of feet of GAC above the bottom laterals.

GAC loss measurement for furnace battery limits--Two methods were employed depending upon the operational status of the furnace.

Furnace not operational--

1. Transfer GAC from a contactor or a filter to spent storage tank (ST1).

2. Prior to beginning the regeneration process, measure the contour of GAC (and possibly sand) in ST1 with a leveling rod at 30.5 cm (1 ft) increments along a square grid placed on top of ST1. The volume of GAC was determined using the following method referred to as the "borrow-pit" method. The horizontal and vertical lines form a grid of square and triangular sections. The squares have an area of 930 sq cm (1 sq ft) and the varying triangular sections around the circular tank wall have areas which were computed individually. The depth to the GAC surface at each section's vertex is averaged and multiplied by the section area to compute the volume of carbon (volume of tank - calculated volume = carbon volume). All individual sections are then summed to obtain the total volume of GAC in the tank. Also prior to regeneration, ensure that an empty sand hopper is in place.

3. Regenerate the GAC in ST1 as a batch until ST1 is empty and the regenerated storage tank (ST2) is full.

4. Place the furnace on idle heat and measure the contours of ST2 in the same fashion that ST1 was measured.

5. Determine the volume of sand in the sand hopper.

6. Determine the volume of GAC in ST1 and ST2 according to the "borrow-pit" method described earlier.

Furnace operational--

1. Transfer GAC from a contactor or filter to ST1.
2. Regenerate the GAC in ST1 until the edge of the GAC in ST2 is above the conical section of ST2 (in the cylindrical portion).
3. With the furnace operating, measure the contours of ST1 and ST2 using the grids and leveling rod identified above. At the start of these measurements, an empty sand hopper should be placed in the regeneration system.
4. Regenerate the GAC in ST1 until the level of ST1 is just above the cone at the sidewall.
5. With the furnace operating, again measure ST1 and ST2 as before.
6. Determine the sand volume in the sand hopper.
7. Determine the volume of GAC in ST1 and ST2 according to the "borrow-pit" method described earlier.

Transport loss measurement--

1. Remove gate from the rotary valve at the bottom of ST1 (Figure 12).
2. Bypass the dewatering screw, furnace and quench tank by running the discharge from the eductor on ST1 to the GAC inlet line on ST2.
3. Backwash and measure the GAC level in the contactor.
4. Transfer as much GAC as possible from the contactor to ST1.
5. Transfer the GAC from ST1 to ST2.
6. Transfer the remainder of the GAC from the contactor to ST1.
7. After the contactor has been flushed, add water to cushion the returning GAC.
8. Transfer GAC from ST2 to the contactor.
9. When transfer is complete, backwash and measure the GAC depth.

GAC loss calculation--Formulas used to calculate GAC losses from measurements taken according to procedures described above are listed below along with definitions of terms.

Exhausted Bed Volume (EBV) - Volume in cu ft of GAC in system just before regeneration, based on the measured GAC depth after backwashing.

Regenerated Bed Volume (RBV) - Volume in cu ft of GAC in system after regeneration, based on the measured GAC depth after backwashing.

Volume of Materials Removed (VMR) - In a contactor, the same as the Regenerated Bed Volume. In a filter, the difference in cu ft between the freeboard measurements before and after removing GAC (and some sand) for regeneration.

Sand Volume Removed (SVR) - Volume in cu ft of sand discharged from the sand separators.

OI = original interface (in), the distance between the top of the washwater trough and the bed surface before GAC added.
EF = exhausted freeboard (in), the distance between the top of the washwater trough and the bed surface before materials removed for regeneration.
NI = new interface (in), the distance between the top of the washwater trough and the bed surface after materials removed for regeneration.
RF = regenerated GAC freeboard (in), the distance between the top of the washwater trough and the bed surface after regenerated GAC returned to filter.

GAC filter Exhausted Bed Volume	EBV = (OI - EF) (1400/12) = cu ft
GAC filter Volume of Materials Removed	VMR = (NI - EF) (1400/12) = cu ft
GAC filter Regenerated Bed Volume	RBV = (NI - RF) (1400/12) = cu ft
GAC Filter Bed Volume Loss (%)	$\mathrm{BVL} = \left(\frac{\mathrm{VMR} - \mathrm{RBV} - \mathrm{SVR}}{\mathrm{VMR} - \mathrm{SVR}}\right) 100$
Contactor Volume of Materials Removed	VMR = EBV = (EF) (95) + 136 = cu ft

Contactor
Regenerated
Bed Volume

$$\text{RBV} = (\text{RF})\,(95) + 136 = \text{cu ft}$$

Contactor
Bed Volume
Loss (%)

$$\text{BVL} = \frac{(\text{VMR} - \text{RBV})}{\text{VMR}}\;100$$

Note: Multiplier to convert cubic feet to cubic meters is 0.028.

LABORATORY

Sampling Plan Overview

Throughout this and later sections, reference will be made to phase and run. Phases have been previously explained in the Introduction. The term "run" is used to describe the period of time that a GAC system was on line between start-up and regeneration. A numbering system was used to describe any particular run, e.g. 3-0 or 3-1. The "3" identifies the phase. The "0" or "1" identifies the run, with "0" meaning virgin GAC and "1" meaning once regenerated GAC. The dictionary contained in Appendix A describes other combinations.

Once the organics laboratory was established and three sand filters were converted to GAC as detailed in Section 4, the project was ready to begin. A sampling and analytical plan was establishedand the GAC filters were put into operation. The locations of the sample points utilized for the study are indicated in Figures 5, 7, 9, 14 and 15. The first two phases of the project, in addition to accomplishing specific objectives also provided experience which helped make the most important third phase even more successful.

Phase 1: Full-Scale GAC Filters --

This initial phase of the work was dedicated to evaluating various GAC filter configurations with respect to both GAC depths and GAC types.

The runday schedule for this phase can be found in Table 15. Sample point locations and sample plan overview can be found in Figures 14 and 15 and in Table 16. Samples were often collected on a more frequent basis than listed in Table 16. For a more precise sampling schedule, refer to the data listing located in Volume 3.

Phase 2: Pilot Scale GAC Systems--

Pilot GAC Filter--In this portion of Phase 2, pilot GAC filters were utilized to compare virgin bituminous-based GAC to regenerated bituminous-based GAC. The comparison extended through two regeneration cycles. Glass columns 7.6 cm (3 in) in diameter were used. Each contained 76 cm (30 in)

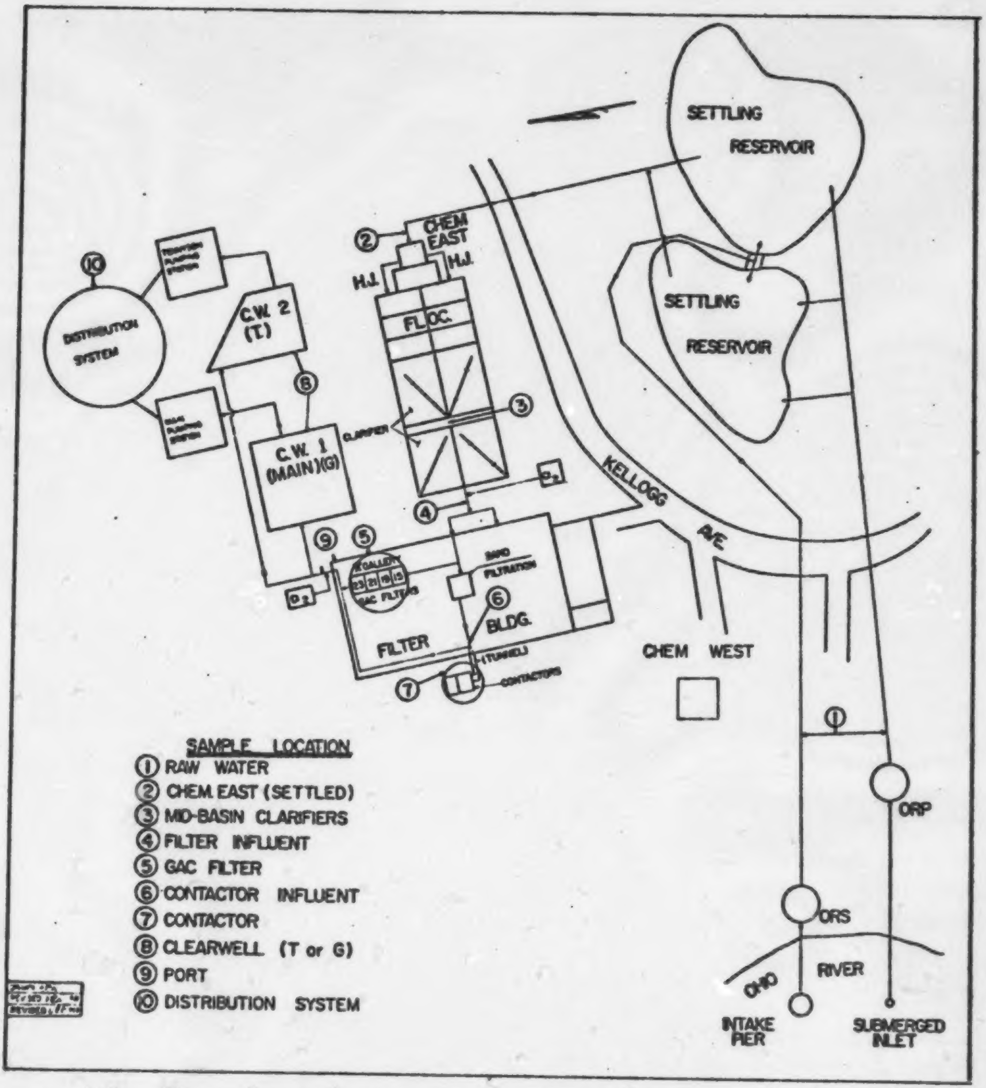
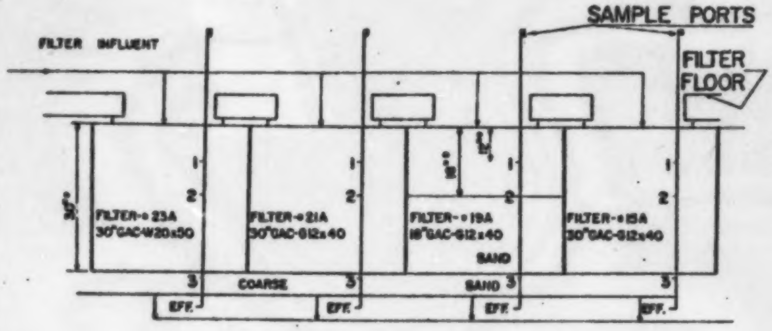
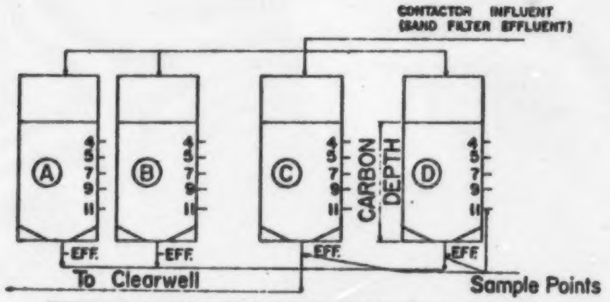

SETTLING
RESERVOIR
SETTLING
RESERVOIR
CHEM
EAST
H.J.
H.J.
FLOC.
CLARIFIER
DISTRIBUTION
SYSTEM
C.W. 2
(T)
C.W. 1
(MAIN)(G)
GALLERY
23 21 19 15
GAC FILTERS
SAND
FILTRATION
BLDG.
FILTER
(TUNNEL)
CONTACTORS
KELLOGG
AVE.
CHEM WEST
ORP
ORS
OHIO
RIVER
INTAKE
PIER
SUBMERGED
INLET
SAMPLE LOCATION
① RAW WATER
② CHEM. EAST (SETTLED)
③ MID-BASIN CLARIFIERS
④ FILTER INFLUENT
⑤ GAC FILTER
⑥ CONTACTOR INFLUENT
⑦ CONTACTOR
⑧ CLEARWELL (T or G)
⑨ PORT
⑩ DISTRIBUTION SYSTEM

Figure 14. Treatment process sample point locations.


SAMPLE PORTS
FILTER INFLUENT
FILTER FLOOR
30"
18"
1
2
3
FILTER-#23A
30"GAC-W20x50
FILTER-#21A
30"GAC-G12x40
FILTER-#19A
18"GAC-G12x40
SAND
FILTER-#15A
30"GAC-G12x40
COARSE
SAND
EFF.

SAMPLE POINT DEPTH		
LOCATION	DEPTH	CONTACT TIME (min)
1	.30M (12")	2.99
2	.46M (18")	4.49
3	.76M (30")	7.48
EFF	.76M (30")	7.48
Loading Rate	101.8 L/M^2 (2.5gpm/ft^2)	* Sample Points Used

CARBON FILTERS SAMPLE COLLECTION POINTS


CONTACTOR INFLUENT
(SAND FILTER EFFLUENT)
A
B
C
D
4
5
7
9
11
CARBON DEPTH
EFF.
To Clearwell
Sample Points

SAMPLE POINT DEPTH		
LOCATION	DEPTH	CONTACT TIME (min)
4 *	.87M (34.2")	2.83
5	1.3M (51.5")	4.36
7 *	2.2M (84.8")	7.17
9 *	3.2M (127.2")	10.77
11	4.1M (162.8")	13.77
EFF *	4.6M (180.0")	15.23
Loading Rate	300.3 L/M^2 (7.37gpm/ft^2)	* Sample Points Used

GAC CONTACTORS SAMPLE COLLECTION POINTS

Figure 15. Full-scale GAC system sample point locations.

TABLE 15. PHASE, RUN, RUNDAY SCHEDULE

GAC System[a]	Phase-Run[a]	Run Start Date	Run Stop Date	Length of Run days
15A	3-0	01/14/80	07/14/80	181
15A	3-1	08/11/80	09/26/80	46
15A	3-2	10/20/80	12/02/80	44
15A	3-3	12/22/80	02/24/81	64
15A	3-4	03/23/81	10/07/81	198
19A	1-0	02/14/78	03/21/80	766
21A	1-0	02/14/78	04/22/80	799
21A	3-1	07/28/80	09/09/80	43
21A	3-2	10/06/80	01/12/81	98
21A	3-3	02/09/81	09/04/81	207
23A	1-0	02/14/78	10/07/80	967
A	3-0	10/01/79	08/19/80	323
A	3-1	09/15/80	12/30/80	106
B	3-0	10/29/79	06/17/80	231
BB	3-0	06/23/80	10/14/80	113
BB	3-1	11/03/80	03/16/81	133
C	3-0	12/17/79	07/29/80	225
C	3-1	08/11/80	11/12/80	93
D	3-0	01-14/80	08/07/80	206
D	3-1	09/01/80	12/16/80	106
D	3-2	12/29/80	05/06/81	128
PFA5	2-0	10/24/78	06/18/79	237
PFA5	3-0	01/14/80	08/07/80	206
PFA5	3-1	09/01/80	12/16/80	106
PFA5	3-2	12/29/80	05/06/81	128
PFA9	2-0	10/24/78	06/18/79	237
RV3	2-1	10/24/78	03/09/79	137
RV3	2-2	05/14/79	09/14/79	123
RV3	3-1	08/11/80	09/26/80	46
RV3	3-2	10/20/80	12/02/80	44
RV3	3-3	12/22/80	02/24/81	64
RV5	2-1	10/24/78	03/09/79	137
RV5	2-2	05/14/79	09/14/79	123
RV5	3-0	01/14/80	07/14/80	182

[a] For description of GAC system and Phase-Run refer to Appendix A.

TABLE 16. PHASE 1 SAMPLE PLAN OVERVIEW[a]

Location	TOC	ITTT	FTTT	STT7	Purg Non Halo	B/N Extr	TEMP	DO	PH	TURB	Cl_2 Free Comb Tot	ODOR	Bact SPC and TCOL	TSOL and TSF
RAW	1	1	1	1	1[h]	i	2	1/mo	2	2	-	2	1	1
SETT	1	1	1	1	-	-	2	-	2	2	-	-	-	-
FLIN	2	2	2[g]	1	1[h]	i	2	2	2	2	2	2	2	1
19A1	2[bc]	1[d]	1[e]	1[f]	-	-	-	1	1[c]	-	1[c]	-	-	-
19A2	2[b]	1	1	1	1[h]	-	-	2	1	-	1	2	2	-
19AE	2	2	2[g]	1	1[h]	i	-	2	2	2	2	-	2	-
21A1	2[bc]	1[d]	1[d]	1[f]	-	-	1	2	1[c]	-	1[c]	-	-	-
21A2	2[b]	1	1	1	1[h]	-	1	2	1	-	1	-	-	-
21A3	2[bc]	1[d]	1[e]	1[f]	-	-	1	2	1[c]	-	1[c]	2	2	-
21AE	2	2	2[g]	1	1[h]	i	1	2	2	2	2	-	2	-
23A1	2[bc]	1[d]	1[e]	1[f]	-	-	-	2	1[c]	-	1[c]	-	-	-
23A2	2[b]	1	1	1	1[h]	-	-	2	1	-	1	-	-	-
23A3	2[bc]	1[d]	1[e]	1[f]	-	-	-	2	1[c]	-	1[c]	2	2	-
23AE	2	2	2[g]	1	1[h]	i	-	2	2	2	2	-	2	-
SFEF	1	1	1	1	-	-	1	-	2	2	2	-	-	-
CT	1	1	1	1	-	-	2	-	2	2	2	2	daily	1
DIST	1	1	1	-	-	-	-	-	-	-	-	-	-	-

[a] Samples of frequencies in table are "per week" except where otherwise noted. For explanation of abbreviations refer to Appendix A.

[b] Samples collected 1/week after 3/28/78.

[c] Sampling discontinued after 5/9/78.

[d] Sampling discontinued after 3/21/78.

[e] Sampling discontinued after 3/7/78.

[f] Sampling discontinued after 3/14/78.

[g] Samples reduced to 1/week after 4/25/78.

[h] Samples collected and stored until a contract was secured with the University of Cincinnati. Unfortunately, few samples were analyzed once the contract was secured due to problems encountered using the USEPA recommended method.

[i] Samples collected 3/3/78, 5/23/78, and 6/20/78. Only the 3/3/78 sample was analyzed.

of Westvaco Nuchar WVG 12 x 40 GAC and had an empty bed contact time (EBCT) of 7.8 min at an hydraulic loading of 1.7 lps/sq m (2.5 gpm/sq ft). The sample ports were referred to as Regenerated/Virgin (RV) for identification of samples.

Pilot Contactors--In this portion of Phase 2, twin pilot contactors were operated in parallel to compare bituminous-based GAC to lignite-based GAC. One column contained 4.57 m (15.0 ft) of Westvaco Nuchar WVG 12 x 40 bituminous-based GAC. The other contained 4.57 m (15.0 ft) of ICI Hydrodarco 1030, a lignite-based GAC. Both columns were 10.2 cm (4 in) diameter and had an EBCT of 16 min at a hydraulic loading of 0.78 lps/sq m (7 gpm/sq ft). Both columns had ports located at various depths for sampling purposes, referred to as Post Filter Adsorbers (PFA) for identification of samples.

The runday schedule for Phase 2 can be found in Table 15. Sample point locations can be found in Figures 5, 7, and 9 and the sample plan overview in Table 17. Samples were often collected on a more frequent basis than detailed in Table 17. For a more precise sampling schedule, refer to the data listing located in Volume 3.

Phase 3: Pilot and Full-Scale Contactors and GAC Filters With On-Site Regeneration--In this phase, contactors operated simultaneously with GAC Filters 21A and 15A. Also during this phase, a pilot GAC filter was run in parallel with GAC Filter 15A and a pilot contactor in parallel with Contactor D.

Four contactors, A, B, C and D, were constructed. Each had a rated capacity of 0.04 cu m/s (1 mgd) at a hydraulic loading of 5.03 lps/sq m (7.41 gpm/sq ft). The contactors received effluent water from the normal sand filters (SFEF). Each contactor contained 4.6 m (15 ft) of Westvaco Nuchar WVG 12 x 40 GAC and had an EBCT of 15.2 min. Filters 21A and 15A contained the same type and grade of GAC as the pilot units with each having an EBCT of 7.5 min. After Phase 3-0, the spent GAC from Contactor B was removed and replaced with virgin GAC and subsequently referred to as Contactor BB.

During Phase 3 an attempt was made to maximize the use of currently available organic techniques rather than restricting the monitoring to the small number of currently regulated contaminants included in the Interim Primary Drinking Water Regulation[1]. This approach provided a broader assessment of the usefulness of GAC for water treatment for organic contaminants. Specifically, the purpose in performing the broader scope of analyses was three fold:

1. A data base of the occurrence of numerous specific organic compounds was provided that was useful in defining whether a problem substance occurred with a sufficient degree of frequency and concentration to merit concern.

TABLE 17. PHASE 2 SAMPLE PLAN OVERVIEW[a]

Location	TOC	ITTT	FTTT	STT7	Purg Non Halo	B/N Extr	TEMP	DO	PH	TURB	Cl_2 Free Comb Tot	ODOR	Bact SPC and TCOL	TSOL and TSF
RAW	1/mo	1/day	1/mo	1/mo	1/mo[c]	-	1/mo	1/mo	1/mo	1/mo	-	1/mo	1/mo	1/mo[e]
SFEF	2	2	1	1	1/mo[c]	d	1	1	1	1	1	1	1	-
PFA2	2[b]	2[b]	1[b]	1[b]	1/mo[c]	-	-	-	-	-	-	-	-	-
PFA3	2	2	1	1	1/mo[c]	-	-	-	-	-	-	-	-	-
PFA4	2[b]	2[b]	1[b]	1[b]	1/mo[c]	-	-	-	-	-	-	-	-	-
PFA5	2	2	1	1	1/mo[c]	d	1	1	1	1	1	1	1	-
PFA6	2[b]	2[b]	1[b]	1[b]	1/mo[c]	-	-	-	-	-	-	-	-	-
PFA7	2	2	1	1	1/mo[c]	-	-	-	-	-	-	-	-	-
PFA8	2[b]	2[b]	1[b]	1[b]	1/mo[c]	-	-	-	-	-	-	-	-	-
PFA9	2	2	1	1	1/mo[c]	d	1	1	1	1	1	1	1	-
FLIN	2	2	1	1	1/mo[c]	d	1	1	1	1	1	1	1	1[e]
RV3	2	2	1	1	1/mo[c]	d	1	1	1	1	1	1	1	-
RV5	2	2	1	1	1/mo[c]	d	1	1	1	1	1	1	1	-
DIST	1/mo	1/mo	-	-	-	-	-	-	-	-	-	-	-	-

[a] Sampling frequencies in table are "per week" except where otherwise noted. For explanation of abbreviations refer to Appendix A.

[b] Sampling discontinued after 5/8/79.

[c] Samples collected and stored until a contract was secured with the University of Cincinnati. Unfortunately, very few samples were analyzed once the contract was secured due to problems encountered using the EPA recommended method.

[d] Samples collected only once on 5/13/79.

[e] Sampling discontinued after 1/16/79.

2. The degree of removal of many specific compounds achieved by a given unit process in an ambient environment was determined.

3. The potential for using some easily measured general organic parameters as operating surrogates in lieu of the more specific, and often more costly, test could be evaluated.

The runday schedule for Phase 3 can be found in Table 15. The sample locations can be found in Figures 5, 7, 9, 14 and 15 and the sample plan overview in Table 18. Samples were often collected on a more frequent basis than detailed in Table 18. For a more precise sampling schedule, refer to the data listings located in Volume 3.

Analytical Procedures

Total Organic Carbon--

The TOC was analyzed using a Dohrmann Envirotech DC-54 Ultra Low Level TOC analyzer. The method used was as described in the DC-54 manual[8] with the following variations:

1. Double-distilled water was prepared using an AG-3 Corning all glass still.

2. The instrument blank was determined by recycling a double-distilled water run.

3. The POC-2 sparger, P/N 511-220, was used because of the presence of particulate matter in some of the samples.

4. Samples with a TOC value greater than 3.0 mg/l were rerun using 300 ul of persulfate reagent per 8.0 ml sample. This provides sufficient reagent for TOC levels of up to 10.0 mg/l.

The following gases were used: hydrogen, grade zero; helium, grade five; and air, grade zero.

Purgeable Halogenated Organics--

Three water samples from various locations were collected that were ultimately analyzed for halogenated organics. Four data elements resulted from these three samples:

1. The instantaneous trihalomethane (INSTTHM) sample was analyzed to determine the concentrations of the four THMs, chloroform ($CHCl_3$), bromodichloromethane ($CHBrCl_2$), dibromochloromethane ($CHBr_2Cl$) and bromoform ($CHBr_3$) present at the time of sampling. The summation of the concentrations of these four individual THMs represented the total THM concentration. This sample was analyzed for eight other purgeable

TABLE 18. PHASE 3 SAMPLE PLAN OVERVIEW[a]

Location	TOC	ITTT	FTTT	STT3	Purg. Non Halo[o]	B/N Extr	Grob CLSA	Acid Extr	CAOX	Pest	Temp	DO	PH and TURB	Cl_2 Free Comb Tot	ODOR	Bact SPC and TCOL
RAW	1	1	1/mo	1/mo	1	1/mo[c]	-	-	-	m	-	-	1	-	1	1
SFEF	1	1	1	1	1	1/mo[c]	1/mo	1/mo[g]	1/mo	m	1	1	1	1	-	1
A4	1	1[i]	1[i]	1[i]	1[i]	-	-	-	-	-	-	-	-	1[i]	-	-
A7	1	1[i]	1[i]	1[i]	1[i]	-	-	-	-	-	-	-	-	1[i]	-	-
A9	1[j]	1[i,j]	1[i,j]	1[i,j]	1[i,j]	-	-	-	-	-	-	-	-	1[i]	-	-
AE	1	1[k]	1[k]	1[k]	1[k]	1/mo[c]	1/mo	1/mo[e]	1/mo	-	-	-	1	1	-	1
B4	1	1	1	1	-	-	-	-	-	-	-	-	-	1	-	-
B7	1	1	1	1	-	-	-	-	-	-	-	-	-	1	-	-
B9	1	1	1	1	-	-	-	-	-	-	-	-	-	1	-	-
BE	1	1	1	1	1	1/mo[c]	-	-	-	-	-	-	1	1	-	1
BB4	1	1	1	1	1	-	-	-	-	-	-	-	-	1	-	-
BB7	1	1	1	1	1	-	-	-	-	-	-	-	-	1	-	-
BBE	1	1	1	1	1	-	-	-	-	-	-	-	1	1	-	1
C4	1	1[d,e]	1[d,e]	1[d,e]	1[d,e]	-	-	-	-	-	-	-	-	1[d,e]	-	-
C7	1	1	1	1	1	-	-	-	-	-	-	-	-	1	-	-
CE	1	1	1	1	1	-	-	-	-	-	-	-	1	1	-	1
D4	1	1	1	1	1	-	-	-	-	-	-	-	-	1	-	-
D7	1	1	1	1	1	-	-	1/mo[f]	1/mo[n]	-	-	-	-	1	-	-
DE	1	1	1	1	1	1/mo[c]	-	1/mo[g]	1/mo	m	1	1	1	1	-	1
PFA2	1	1	1	1	1	-	-	-	-	-	-	-	-	1	-	-
PFA3	1	1	1	1	1	-	-	-	-	-	-	-	-	1	-	-
PFA5	1	1	1	1	1	1/mo[c]	-	1/mo	1/mo	m	1	1	1	1	-	1
FLIN	1[b]	1	1	1[b]	1	1/mo[c]	-	1/mo[h]	1/mo	m	1	1	1[b]	1[b]	-	1
21AE	1[b]	1	1	1[b]	1	-	-	-	-	-	-	-	1[b]	1[b]	-	1
15AE	1[b]	1	1	1[b]	1	1/mo[c]	-	1/mo[h]	1/mo	m	1	1	1[b]	1[b]	-	1
RV3	1	1	1	1	1	-	-	1/mo	1/mo	-	1	1	1	1	-	1
RV5	1	1	1	1	1	1/mo[c]	-	1/mo	1/mo	m	1	1	1	1	-	1
Port	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
CT	-	-	-	-	-	-	-	-	-	-	1	1	1	1	1	1
DIST	1	1	-	-	-	-	-	-	-	-	1	-	1	1	-	-

[a] Sample frequencies in table are "per week" except where otherwise noted. For explanation of abbreviations refer to Appendix A.

[b] As the GAC filter approached exhaustion the samples were collected twice a week. This was performed only on short GAC filter runs.

[c] The B/N extractable samples were collected but not analyzed on 10/2/79, 10/30/79, and 11/27/79. Analysis started with the 12/4/79 samples. Sampling for B/N extractables was discontinued after six months. It appeared that most of the identifications were laboratory artifacts.

[d] Samples collected from Phase 3-1 on.

[e] Samples collected only during Phase 3-0.

[f] Samples not collected during Phase 3-1. During Phase 3-2 samples collected 2/month.

[g] Samples collected 2/month during Phase 3-2.

[h] Samples collected 2/month during Phase 3-3.

[i] Samples not collected after run day 99 during Phase 3-0. Sampling resumed in Phase 3-1.

[j] Samples collected during Phase 3-0 only.

[k] Samples collected 1/2 weeks after run day 162 during Phase 3-0.

[l] Samples collected 1/2 weeks during Phase 3-1 and 3-2.

[m] Samples collected 1/15/80 and 2/12/80.

[n] Samples not collected during Phase 3-1.

[o] Samples collected after 8/1/80 analyzed by CWW.

halogenated compounds: dichloromethane, carbon tetrachloride, 1,2-dichloroethane, trichloroethylene, tetrachloroethylene, 1,1,1-trichloroethane, chlorobenzene, and o-dichlorobenzene.

2. The simulated distribution THM (THMSIMDIST) sample resulted in an estimate of the THM concentration which would be found in the distribution system (with or without GAC treatment).

   The THMSIMDIST sample was dosed with excess free chlorine and stored under controlled conditions. Chlorine dose, pH, temperature and storage or reaction time were controlled to match those present in the actual distributed water at the time of sampling. After the specified storage time, the THMSIMDIST concentration was measured. This measurement assisted in evaluating the effect of GAC treatment on the actual quality of distributed water.

3. The maximum THM (THMMAX) sample resulted in a measure of the THM concentration found at the end of a set time period having been held under controlled conditions. The THMMAX sample was dosed with excess free chlorine residual and treated similarily to the THMSIMDIST sample except that the storage conditions were constant and represented the maximum conditions experienced in the Cincinnati distribution system.

4. THM formation potential (THMFP) was a practical measure of the precursor concentration, generally regarded as aquatic humic materials, present at the time of sampling.[9] For this data element determination, the INSTTHM sample concentration was subtracted from a THMMAX sample concentration.

Sample preparation--

INSTTHM--This sample was collected in a muffled 40 ml screw cap vial in the presence of sodium sulfite to chemically reduce chlorine residual thus arresting further formation of THMs.

THMSIMDIST--This procedure involved placing the sample in a 325 ml glass stoppered amber bottle containing pH 8.2 boric acid - borax buffer and sufficient calcium hypochlorite solution to result in an additional free chlorine residual of 2.5 mg/l. The bottles were then stored in an insulated waterbath for three days. Finished water from the water treatment plant continuously passed through the waterbath to maintain the temperature of the samples at plant finished water temperature. After the proper storage period, the THM reaction was stopped by collecting a sample in a muffled 40 ml screw cap vial containing sodium sulfite. The sample was then analyzed to determine the THMSIMDIST concentration.

During Phases 1 and 2 the storage or reaction time was seven days. This seven-day storage time was thought to represent the travel time necessary to reach the remote points of the distribution system. However, a subsequent test utilizing fluoride as an indicator showed a travel time of three days to the most remote points of the Cincinnati distribution system. Therefore, during Phase 3, a three-day storage time was used.

THMFP--This procedure involved placing a THMMAX sample in a 325 ml glass stoppered amber bottle containing pH 9.5 borax-NaOH buffer and sufficient calcium hypochlorite solution to result in an additional free chlorine residual of 15 mg/l. The bottles were then stored at 29.4°C (85°F) for seven days after which time the THM reaction was stopped by collecting a sample in a muffled 40 ml screw cap vial containing sodium sulfite. The THMFP was determined by subtracting the INSTTHM concentration, determined earlier, from the THMMAX concentration.

Sample analysis--Purgeable halogenated organics were measured by the USEPA purge/trap THM analytic procedure[10]. THM and similar volatile compounds were stripped from a 5 ml water sample with a 40 ml/min stream of helium for 11 minutes. The organics were collected on a trap of Tenax-GC. The adsorbed organics were backflushed for six minutes at 200°C (329°F) with helium at 50 ml/min and collected on a cool, 40°C (104°F) gas chromatographic packed column. This process was facilitated by the use of a Tekmar LSC-1 liquid sample concentrator and a Varian 3700 GC. The chromatographic column was a 1.8 m (6 ft) x 2 mm ID glass column packed with 0.4% Carbowax 1500 on Carbopack-A (80/100 mesh). The chromatogram was then developed by temperature programming to 175°C (347°F) at a rate of 6°C/min (11°F/min) and held for eight minutes. A Hall Model 700 electrolytic conductivity detector in the halogen specific mode was used for detection.

Purgeable Non-Halogenated Organic Compounds--

Analyses for purgeable non-halogenated compounds were initially performed by the University of Cincinnati (UC) with CWW eventually taking over the analyses. The purgeable non-halogenated compounds of interest included: hexane, ethylbenzene, benzene, o-xylene, toluene and 1,2,3,4 -tetrahydronapthalene (tetralin).

UC employed a modification of the USEPA purge/trap THM method[10] and experienced many problems. Unfortunately, the results from the samples analyzed using this method were not reliable.

The following method was used by UC. The volatile compounds were stripped from a 10 to 20 ml volume, contained in a 50 ml purge device, with a 40 ml/min stream of ultra-pure nitrogen for 11 minutes. The organics were collected on a trap of Tenax-GC. The trap was then placed in the carrier gas system of a Varian 1700 GC by means of quick-connectors. A heating tape was wrapped around the trap. The adsorbed organics were backflushed for six minutes at 230°C (446°F) with ultra-pure nitrogen onto a 60°C (140°F) Chromosorb 101 column. The chromatogram was then developed by rapidly heating the column oven to 125°C (257°F), holding for six minutes and then temperature programming to 220°C (428°F) at a rate of 6°C/min (11°F/min).

The following method was used at CWW. The volatile compounds were stripped from a 5 ml water sample with a 40 ml/min stream of helium for 11 minutes. The organics were collected on a trap of Tenax-GC. The adsorbed organics were backflushed for six minutes at 180°C (356°F) with helium at 50 ml/min and collected on a 60°C (140°F) gas chromatographic packed column. This process was facilitated by the use of a Chemical Data System Inc., Model 310, concentrator and a Varian 3700 GC. The chromatographic column was a 1.83 m (6 ft) x 2 mm ID glass column packed with 1% SP 1000 on Carbopack B (60/80 mesh). The chromatogram was then developed by temperature programming to 200°C (392°F) at a rate of 10°C/min (18°F/min) and held for 33 minutes. An FID was used for detection.

Acid Extract Capillary Column GC/FID Profiles--

Organic profiles were generated by a liquid/liquid extraction of 3.8 l (1 gal) samples adjusted to pH 2 with hydrochloric acid. Fresh volumes of 250, 100, and 100 ml of dichloromethane were shaken consecutively with the sample in a six liter separatory funnel, combined after separation, dried with anhydrous sodium sulfate, and reduced in volume by boiling to 0.5 ml by use of the Kuderna-Danish apparatus. One ug of anthracene (corresponding to 0.25 μg/l in the original sample) was added to the final volume after concentration as an internal standard. Blanks corresponding to each batch of redistilled solvent with internal standard added were also analyzed. Analysis was initially performed by the USEPA, Cincinnati, Ohio using a microprocessor controlled GC (H.P. Model 5840) equipped with a splitless capillary injection system, a 30 m, SP-2100, wall-coated-open-tubular glass capillary column, and a flame ionization detector. Analysis was eventually performed at the CWW using a Varian 3700 GC equipped as stated above except with a fused-silica capillary column and a Spectra Physics SP4100 computing integrator.

Gas Chromatograph/Mass Spectrometer (GC/MS) Identification of Acid Extract Compounds--

The primary purpose of the GC/MS was to attempt to identify and establish the frequency of occurrence of high molecular weight compounds before and after full-scale GAC treatment. A secondary purpose was to determine if typical water utility laboratory personnel are capable of operating and maintaining a GC/MS.

A Finnigan Organics in Water (OWA) GC/MS was purchased by CWW. This was new generation equipment and one of the first few sold in the country. This instrument was selected because of its reasonable capital and operating costs and because it was advertized as being capable of operation without the degree of attention required by more sophisticated, high-priced equipment being used in basic research laboratories.

A number of problems were encountered that deferred obtaining useful results from the instrument:

1. Air conditioning in the new laboratory, in which the GC/MS was housed, was not initially operational. Later it was found necessary to add a supportive unit.

2. Replacement of damaged door frames in the new laboratory required shutting down and dust proofing of the instrument for several weeks.

3. Normal software and hardware problems typically experienced with any new generation equipment required, in the aggregate, many months of delays awaiting field visits and parts.

4. Operator training was necessary.

5. GC/MS operator turnover occurred at the peak of the project requiring replacement and subsequent training of a new operator.

6. Upgrading the capillary injector to a Grob-type split/splitless injector was required to permit a more controlled injection.

In spite of the problems mentioned, CWW experiences with the Finnigan, OWA, GC/MS would indicate that water utility staff, who are competent in running and maintaining chromatographic equipment, should be capable of operating a non-research, less sophisticated GC/MS.

The GC/MS intended purpose was to tentatively identify the peaks observed in the acid extract, GC/FID profiles. After the GC/FID capillary column profile was obtained, the acid extract sample was further concentrated to 0.2 ml by passing helium above the sample vial. Analysis was then performed using the GC/MS equipped with a splitless capillary injection system and a 30 m SP-2100 wall-coated-open-tubular, fused-silicon capillary column. Four ul of sample were slowly injected with the splitter off. After 45 seconds, the splitter was opened. The initial oven temperature of 20°C (68°F) was maintained for five minutes. The oven was then programmed to 240°C (464°F) at a rate of 2°C/min (3.6°F/min) and held for 30 minutes.

The GC/MS was used to report only tentative identification of compounds and not concentrations. The USEPA evaluated a Finnigan, OWA, GC/MS[11] using a packed column and reported a lower detection limit of between 10 and 20 ng decafluorotriphenylphosphine (DFTPP). CWW used a capillary column which should be superior to a packed column. The lower detection limits for several phenolic compounds were calculated and found to have a concentration range of 0.002 - 0.13 ng (Table 19). This lower detection limit, along with the fact that the GC/MS was not able to identify many of the compounds observed in the acid extract profiles, should give an indication of the concentrations present.

Carbon Adsorbable Organohalides (CAOX)--

The CAOX method used for carbon adsorbable organohalides was described in detail by Dressman, et al.[12] The CAOX analyses were performed by the

TABLE 19. FINNIGAN GC/MS LOWER DETECTION LIMITS

Compound	Detection Limit[a] (ng)
2-Chlorophenol	0.002
Phenol	0.004
2-Nitrophenol	0.006
2,4-Dimethylphenol	0.004
2,4-Dichlorophenol	0.002
p-Chloro-m-cresol	0.002
2,4,6-Trichlorophenol	0.002
2,4-Dinitrophenol	0.13
4-Nitrophenol	0.026
4,6-Dinitro-o-cresol	0.025
Pentachlorophenol	0.004

[a] Calculated using capillary column.

USEPA, Cincinnati, Ohio. In general, the organic material was adsorbed on 40 mg of activated carbon from a 100 ml sample to which nitric acid had been added to adjust to pH 2 thus improving adsorption of organics. Also, sodium sulfite had been added to chemically reduce the chlorine residual. Adsorption was facilitated by use of a mini-column assembly and a commercially available Dohrmann AD2 adsorption module. Following the adsorption step, the activated GAC was washed with a nitrate solution to remove interference of chloride. Halide ions were formed by combustion of the sample in a controlled atmosphere and measured by microcoulometric titration. This process was accomplished with either a Dohrmann Envirotech MCTS-20 or MC-1 system. Results were expressed in µg/L as chloride.

Grob Closed Loop Stripping--

Sample preparation by a variation of the closed loop stripping analysis (CLSA), first described by Grob,[13,14] followed by glass capillary GC/MS, was considered to be a sensitive and convenient approach to the measurement of individual organic compounds in the intermediate volatility range. The exact method used in this study was described in detail by Coleman, et al.[15] Samples of 3.8 l (1 gal) were purged at 30°C (86°F) for two hours with their own headspace gas continuously recirculating. By use of an inline activated carbon filter, the purged organics were adsorbed from the gas phase. Adsorbed organics were later desorbed from the carbon with microliter quantities of carbon disulfide. Aliquots were then analyzed by GC/MS with results interpreted relative to the appropriate added internal standards.

Base/Neutral Extractables--

Analyses for base/neutral extractable compounds were performed by PEDCo Environmental, Inc. as a contract service. The samples were analyzed for the following compounds: isophorone; napthalene; bis(2-ethylhexyl)phthalate; di-n-butyl phthalate; dimethyl phthalate; diethyl phthalate; nitrobenzene; 2,4-dinitrotoluene; 2,6-dinitrotoluene; aniline; alpha-napthylamine; butylbenzylphthalate; pyridine; alpha-picoline and 2,4-dimethylpyridine.

PEDCo employed the USEPA method[16] for extraction and concentration of the samples with the following exceptions:

1. 1.5 l of the sample were extracted.

2. Samples were first evaporated to less than 5.0 ml using the Kuderna-Danish apparatus then further evaporated to 0.5 ml using a stream of nitrogen.

Subsequent qualitative and quantitative analyses were performed using either a GC/FID or a GC/MS.

Pesticides/Herbicides/Polychlorinated Biphenyls (PCB)--

The Ohio Environmental Protection Agency (OEPA) was asked to participate in the project by analyzing 14 samples for pesticides, herbicides and PCBs. All of these submitted samples showed less than detectable levels for seven parameters: endrin, lindane, methoxychlor, toxaphene, 2,4-D, silvex, and PCBs. The OEPA Industrial Chemical Laboratory used USEPA[17] methods.

Sampling Glassware Preparation for All Organic Analyses--

All glass sample bottles were washed, rinsed, covered with aluminum foil, and heated to 400°C (752°F) for at least 1/2 hour in a muffle furnace. Vials and bottles with Teflon-faced, silicone-rubber septa and plastic screw caps were used for the THM, CAOX, TOC and non-halogenated samples. Bottles of 3.8 l (1 gal), employing plastic screw tops with Teflon liners, were used for the acid extractable organic GC/FID profile, base/neutral extractable organic, pesticide, herbicide and Grob CLSA samples. Samples were returned to the laboratory and stored at 4°C (39°F) until analyzed or otherwise treated prior to analysis. At the time of sampling, sufficient sodium sulfite was added to chemically reduce the chlorine residual thereby preventing further formation of disinfectant by-products (except THMMAX, THMSIMDIST, non-halogenated, base/neutral and pesticide/herbicide/PCB samples). Mercuric chloride was added at approximately 10 mg/l in dry powder form to the 3.8 l (1 gal) Grob CLSA and GC/FID profile samples to retard microbiological activity. Hydrochloric acid was added to the 40 ml non-halogenated sample vial to retard microbiological activity. The chlorine residual in the base/neutral extractable samples was chemically reduced by the addition of sodium sulfite before being extracted.

Reagents--

Chlorine dosing solution--Calcium hypochlorite (0.5 g) was dissolved in 500 ml of helium-stripped, double-distilled water. This resulted in approximately 500 mg/l of free available chlorine.

Chlorine neutralizing solution--0.2 N Sodium sulfite (2.5 g) was dissolved in 100 ml of helium-stripped, double-distilled water with 0.5 ml added to a 40 ml sample vial.

Boric acid/borax, pH 8.2 buffer--A mixture of 3.1 g boric acid and 0.7 g borax was dissolved in one l of helium-stripped, double-distilled water with 15 ml of this buffer added to each 325 ml sample bottle.

Borax, pH 9.5 buffer-- A mixture of 4.8 g borax and 0.7 g sodium hydroxide was dissolved in one l of helium-stripped, double-distilled water with 15 ml of this buffer added to each 325 ml sample bottle.

Bacterial, Physical and Chemical--

The methods used in performing the bacterial, physical and chemical analyses were from "Standard Methods."[18]

Regenerator Off-Gas--

The regenerator specifications required that emissions during the operation would comply with all regulations to the satisfaction of the local air pollution authority. In order to ascertain that this requirement was met, a local laboratory (PEDCo) was engaged to conduct stack gas analysis. All sampling and analytical procedures were conducted in accordance with the methodology protocol set forth in the Federal Register.[19]

Analytical methods used in the evaluation of GAC qualities can be found in Table 20.

Sand in Carbon--

The following procedure[23] was used to determine the ratio of sand to GAC contained in sand table discharges.

1. Prepare 10 g of a dried representative GAC/sand sample by riffling entire sample.

2. Pour 100 ml of a 54% tetrabromoethane and 46% carbon tetrachloride solution into a 500 ml separatory funnel. The funnel should be the open-end variety with a 0.64 cm (1/4 in) opening for use with rubber tubing and a tubing clamp.

3. Pour the sample into the separatory funnel and swirl the sample until particles no longer settle out (approximately one min).

4. Drain off 50 ml of the solution which contains the sand into a 100 ml beaker.

5. Dilute the solution containing the sand with approximately 20 ml of acetone and decant the solution being very careful not to carry over any sand. Repeat this step several times.

TABLE 20. ANALYTICAL METHODS REFERENCE LIST

Test Method	Reference
Iodine Number	5
Molasses Number	5
Decolorizing Index	5
Abrasion Number (Ro-Tap)	5
Apparent Density	5
Sieve Analysis (dry)	5
Effective Size and Uniformity Coefficient	5
Moisture	5
Moisture (Alternate Method)	5
Total Ash	5
BET Total Surface Area	20
Phenol Value - AWWA Modified	21
Phenol Value - Westvaco Modified	22

6. Dry this sample in 100°C (212°F)) oven for at least one hour, cool and weigh in a preweighed aluminum dish.

7. Perform calculation: $\% \text{ sand} = \frac{\text{dry sand wt. (g)}}{\text{original sample wt. (g)}} \times 100.$

Analytical Quality Control--

Bacterial, physical and chemical--The CWW Laboratory and its personnel are certified by the OEPA for physical and chemical analyses under Approval No. 882, and for bacterial analyses under OEPA Approval No. 130.

Once a year, all certified physical and chemical analyses are evaluated under the USEPA quality control standards program. As recommended by OEPA, quality control analyses are continuously performed.

Purgeable halogenated--Purgeable halogenated organics were measured by the USEPA purge/trap THM analytical procedure.[10] The analytical equipment was standardized by the external standard method. If the average response factor for the standard was not within 10% of the previous standard run, the calibration was not accepted. The standard was then rerun until the average response factor was within 5% of the previous run.

The integrity of the analytical procedure throughout the day was checked by performing a duplicate analysis of every tenth sample. A duplicate analysis involved two successive analyses of the same sample. The average percent relative deviations on duplicate THM analyses can be found in Table 21. Percent relative deviation (RD) was calculated by determining the percent difference between the higher of the two data points (A) and their mean ($\bar{X}$), RD = $[(A - \bar{X})/\bar{X}]100$. The average percent relative deviation

TABLE 21. AVERAGE PERCENT RELATIVE DEVIATION OF THM ANALYSES

Duplicate Samples

Concentration (μg/l)	$CHCl_3$, %	$CHBrCl_2$, %	$CHBr_2Cl$, %	$CHBr_3$, %
0.4 - 10	1.87	1.55	1.90	3.26
10 - 100	1.74	1.56	1.45	1.10[a]
100	1.84	-	-	-
Overall Average	1.79	1.56	1.73	3.26

Replicate Samples

Concentration (μg/l)	$CHCl_3$, %	$CHBrCl_2$, %	$CHBr_2Cl$, %	$CHBr_3$, %
0.4 - 10	6.23	6.55	6.03	8.94
10 - 100	4.04	4.15	4.58	-
100	2.98	-	-	-
Overall Average	4.24	4.84	5.55	8.94

[a] Based on one value.

represents the average of the relative deviations of all the data sets in the stated concentration range. Thus, an average percent relative deviation of 1% would mean that the data was only 1% from the mean. An average percent relative deviation of 10% was accepted. The average percent relative deviations from the mean values over the entire range of values were as follows: $CHCl_3$ (1.79), $CHBrCl_2$ (1.56), $CHBr_2Cl$ (1.73) and $CHBr_3$ (3.26). These values show little variability from analysis to analysis and overall excellent precision in the method.

The integrity of the analytical procedure from day to day and, therefore, from standardization to standardization was performed using replicate analyses. A replicate analysis involved the collection of two separate vials at the time of sampling. The two vials were then analyzed on different days and the results obtained based on two different standardizations. One replicate analysis was performed for every 20 samples of each of the following: INSTTHM, THMSIMDIST and THMMAX. The average percent relative deviation of replicate trihalomethane analyses can be found in Table 21. The average percent relative deviations from the mean values over the entire range of values were as follows: $CHCl_3$ (4.24), $CHBrCl_2$ (4.84), $CHBr_2Cl$ (5.55) and $CHBr_3$ (8.94). As expected, these values are slightly higher than the duplicate results but continue to show good precision in the method.

The accuracy of the formation potential procedure was determined using the control sample analysis. Control sample analyses were performed both on the THMMAX samples and on the THMSIMDIST samples. The procedure involved the preparation of two 325 ml bottles, rather than the normal one, according to the corresponding method using the proper chlorine dose, buffer, temperature and time for the two types of formation potentials performed. One vial was collected from each of the sample bottles. The vials were then analyzed in succession on the same day. One control sample analysis was performed on every 20th sample. The average percent relative deviation from control sample THM analyses can be found in Table 22. The average percent deviations from the mean values over the entire range of concentrations for the THMMAX control samples were as follows: $CHCl_3$ (2.17), $CHBrCl_2$ (2.58), $CHBr_2Cl$ (2.67) and $CHBr_3$ (4.32). The average percent deviations from the mean values over the entire range of concentrations for the THMSIMDIST control samples were as follows: $CHCl_3$ (3.17), $CHBrCl_2$ (2.41), $CHBr_2Cl$ (2.20) and $CHBr_3$ (3.84). As expected, these values were between the duplicate and the replicate results and show excellent accuracy in the methods used in the preparation of the control samples.

Evaluation of CWW's ability to correctly identify and quantify organic compounds was accomplished by analyzing USEPA performance standards. Eight USEPA performance evaluation standards were analyzed during the length of the project. The standards consist of two sealed ampules containing various concentrations of unknown volatile halogenated organic compounds. The volatile organic compound concentrates were spiked into organic free water and analyzed.

Three sets of samples were received directly from the USEPA. The results from these samples are contained in Tables 23, 24 and 25 and show that all 31 compounds present in the vials were correctly identified and that their concentrations were within the acceptable limits established. The acceptance limits used were as reported by the USEPA. Table 23 limits

TABLE 22. AVERAGE PERCENT RELATIVE DEVIATION FOR THM CONTROL SAMPLES

Maximum THM

Concentration (µg/l)	$CHCl_3$, %	$CHBrCl_2$, %	$CHBr_2Cl$, %	$CHBr_3$, %
0.4 - 10	2.47	3.12	3.06	4.32
10 - 100	2.05	2.42	2.20	-
100	2.32	-	-	-
Overall Average	2.17	2.58	2.67	4.32

Simulated Distribution System THM

Concentration (µg/l)	$CHCl_3$, %	$CHBrCl_2$, %	$CHBr_2Cl$, %	$CHBr_3$, %
0.4 - 10	3.12	2.88	2.0	3.84
10 - 100	3.57	2.37	2.34	-
100	2.94	-	-	-
Overall Average	3.17	2.41	2.20	3.84

TABLE 23. USEPA PERFORMANCE EVALUATION STANDARDS[a] WP005, MARCH, 1979

Parameter	True Value (µg/l)	Reported Value (µg/l)	Acceptance Limits[b] (µg/l)	Performance Evaluation
Vial 1				
Chloroform	22.8	21.1	0 - 45.1	Acceptable
Bromodichloromethane	2.4	2.7	0 - 8.2	Acceptable
Dibromochloromethane	2.1	1.4	0.1 - 3.4	Acceptable
Bromoform	2.8	2.5	0 - 6.0	Acceptable
Total Trihalomethane	30.1	27.7		
1,2-Dichloroethane	2.1	1.8	0 - 5.9	Acceptable
1,1,1-Trichloroethane	1.7	1.0	0 - 9.8	Acceptable
Carbon Tetrachloride	4.2	3.2	0 - 13.2	Acceptable
Trichloroethylene	1.9	1.7	0 - 6.4	Acceptable
Tetrachloroethylene	1.8	1.6	0 - 4.5	Acceptable
Vial 2				
Chloroform	91.3	83.0	29.8 - 137.0	Acceptable
Bromodichloromethane	23.8	24.8	0 - 55.7	Acceptable
Dibromochloromethane	10.3	8.8	0 - 17.1	Acceptable
Bromoform	11.4	10.1	0.7 - 21.3	Acceptable
Total Trihalomethane	136.8	126.7		
1,2-Dichloroethane	17.3	13.4	4.2 - 32.6	Acceptable
1,1,1-Trichloroethane				
Carbon Tetrachloride	16.8	12.8	0 - 43.3	Acceptable
Trichloroethylene				
Tetrachloroethylene				

[a] Received from USEPA.

[b] Based on 99% confidence interval.

TABLE 24. USEPA PERFORMANCE EVALUATION STANDARDS[a] WS006, FEBRUARY, 1980

Parameter	True Value (µg/l)	Reported Value (µg/l)	Acceptance Limits[b] (µg/l)	Performance Evaluation
Vial 1				
Chloroform	7.5	8.2	6.0 - 8.9	Acceptable
Bromodichloromethane	42.5	46.3	34.0 - 51.0	Acceptable
Dibromochloromethane	17.0	18.5	13.6 - 20.4	Acceptable
Bromoform	81.8	82.9	65.4 - 98.2	Acceptable
Total Trihalomethane	148.8	156.0	119.0 - 179.0	Acceptable
Vial 2				
Chloroform	92.3	99.4	74.6 - 112.0	Acceptable
Bromodichloromethane	4.7	5.1	3.8 - 5.7	Acceptable
Dibromochloromethane	50.9	49.2	40.7 - 61.1	Acceptable
Bromoform	12.3	12.7	9.8 - 14.8	Acceptable
Total Trihalomethane	161.1	166.0	129.0 - 193.0	Acceptable

[a] Received from USEPA.
[b] Based on 20% of true value.

TABLE 25. USEPA PERFORMANCE EVALUATION STANDARDS[a] WS008 MAY, 1981

Parameter	True Value (µg/l)	Reported Value (µg/l)	Acceptance Limits[b] (µg/l)	Performance Evaluation
Vial 1				
Chloroform	76.6	81.5	61.0 - 92.0	Acceptable
Bromodichloromethane	91.2	91.8	73.0 - 110.0	Acceptable
Dibromochloromethane	71.1	72.4	57.0 - 85.0	Acceptable
Bromoform	98.7	102.6	79.0 - 120.0	Acceptable
Total Trihalomethane	337.6	348.0	270.0 - 410.0	Acceptable
Vial 2				
Chloroform	10.2	10.1	8.2 - 12.0	Acceptable
Bromodichloromethane	22.8	24.4	18.0 - 27.0	Acceptable
Dibromochloromethane	11.8	12.2	9.4 - 14.0	Acceptable
Bromoform	32.9	31.2	26.0 - 39.0	Acceptable
Total Trihalomethane	77.7	78.0	62.0 - 93.0	Acceptable

[a] Received from USEPA.
[b] Based on 20% of true values.

were based on a 99% confidence interval while Table 24 and 25 limits were based on 20% of true value. The USEPA switched methods for calculating acceptance limits to 20% because the 99% confidence interval was too large.

Five sets of samples were received from Ohio River Valley Water Sanitation Commission (ORSANCO). These samples were part of the quality assurance program for the Early Warning Organics Detection System (EWODS). These results are contained in Tables 26 through 30. The acceptance limits contained in the tables were calculated using the results from four to ten participating laboratories. A one-way analysis of variance was performed to determine if any of the participating laboratories were outside the population mean. If a significant difference between the laboratories existed, the site or sites were determined using the Duncan Multiple-Range Test and the data not used in further evaluation. The 99% confidence interval from the true value was then calculated using a T-distribution. The T-distribution was used due to the small number of participating laboratories. From the tables, it can be seen that all 98 compounds present were properly identified and in only two cases were the reported concentrations outside the acceptance limits. Both compound concentrations outside the acceptance limits were $CHBr_2Cl$. The true values were 2.7 µg/l and 2.1 µg/l and the reported values 1.8 µg/L and 1.5 µg/l respectively.

Purgeable non-halogenated--Purgeable non-halogenated organics were measured by the purge/trap analytical procedure. The analytical equipment was standardized by the external standard method. If the average response factor for the standard was not within 10% of the previous standard run, the calibration run was not accepted and the standard was rerun. The quality control discussion contained herein applies only to samples analyzed by CWW.

The integrity of the analytical procedure throughout the day and from day to day was checked by performing one duplicate analysis every 10 samples and one replicate analysis every 20 samples. The average percent relative deviations for duplicate and replicate analyses can be found in Table 31. It is apparent that of the compounds which were analyzed, only benzene was found with any regularity. All concentrations were less than 1 ug/l. The analytical procedure shows excellent precision with little variability from analysis to analysis and from day to day.

Total organic carbon--The integrity of the analytical procedure throughout the day was checked by performing a duplicate analysis on every fifth sample. The average percent relative deviation was 2.19. This value shows little variability from analysis to analysis.

The integrity of the analytical procedure from day to day and, therefore, from standardization to standardization was performed using the replicate analyses procedure previously described. The average percent relative deviation for TOC replicate analyses was 4.57. As expected, this value is higher than the duplicate value but still well within acceptable limits.

In order to determine if any short term instrument drift or contamination factors occurred during an analysis day, an 1,800 µg/l standard was run

TABLE 26. USEPA PERFORMANCE EVALUATION STANDARDS[a], MARCH, 1979

Parameter	True Value (µg/l)	Reported Value (µg/l)	Acceptance Limits[b] (µg/l)	Performance Evaluation
Vial 1				
Chloroform	22.8	21.3	4.2 - 41.4	Acceptable
Bromodichloromethane	2.4	3.0	0 - 6.2	Acceptable
Dibromochloromethane	2.1	1.5	0.1 - 4.1	Acceptable
Bromoform	2.8	3.2	0 - 6.8	Acceptable
Total Trihalomethane	30.1	29.0	6.2 - 54.0	Acceptable
1,2-Dichloroethane	2.1	2.0	0 - 6.3	Acceptable
1,1,1-Trichloroethane	1.7	1.1	0 - 7.1	Acceptable
Carbon Tetrachloride	4.2	3.4	0 - 14.8	Acceptable
Trichloroethylene	1.9	1.4	0 - 10.6	Acceptable
Tetrachloroethylene	1.8	1.8	0 - 6.2	Acceptable
Vial 2				
Chloroform	91.3	85.4	40.8 - 130.0	Acceptable
Bromodichloromethane	23.8	24.5	0 - 81.0	Acceptable
Dibromochloromethane	10.3	8.6	0 - 21.4	Acceptable
Bromoform	11.4	9.8	0 - 85.1	Acceptable
Total Trihalomethane	136.8	128.3	0 - 278.4	Acceptable
1,2-Dichloroethane	17.3	14.6	0 - 63.5	Acceptable
1,1,1-Trichloroethane				
Carbon Tetrachloride	16.8	15.4	0 - 88.4	Acceptable
Trichloroethylene				
Tetrachloroethylene				

[a] Received from Orsanco EWODS.
[b] Based on 99% confidence interval.

TABLE 27. USEPA PERFORMANCE EVALUATION STANDARDS[a], APRIL, 1979

Parameter	True Value (μg/l)	Reported Value (μg/l)	Acceptance Limits[b] (μg/l)	Performance Evaluation
Vial 1				
Chloroform	9.1	8.0	0.2 - 18.0	Acceptable
Bromodichloromethane	1.2	1.4	0 - 5.1	Acceptable
Dibromochloromethane	2.7	1.8	2.1 - 3.3	Not Acceptable
Bromoform	2.8	2.3	1.9 - 3.7	Acceptable
Total Trihalomethane	15.8	13.5	4.8 - 26.8	Acceptable
1,2-Dichloroethane	1.4	1.2	0 - 3.6	Acceptable
1,1,1-Trichloroethane				
Carbon Tetrachloride	1.7	1.3	0.9 - 2.5	Acceptable
Trichloroethylene				
Tetrachloroethylene				
Vial 2				
Chloroform	68.5	69.0	37.9 - 99.1	Acceptable
Bromodichloromethane	11.9	15.2	0 - 31.6	Acceptable
Dibromochloromethane	17.2	15.4	10.0 - 24.3	Acceptable
Bromoform	14.2	12.9	8.4 - 20.0	Acceptable
Total Trihalomethane	111.8	112.5	56.7 - 166.9	Acceptable
1,2-Dichloroethane	27.2	21.6	18.4 - 36.0	Acceptable
1,1,1-Trichloroethane	11.2	9.8	6.9 - 15.5	Acceptable
Carbon Tetrachloride	12.6	10.9	2.7 - 22.5	Acceptable
Trichloroethylene	19.0	15.6	7.9 - 30.1	Acceptable
Tetrachloroethylene	8.8	8.9	6.4 - 11.2	Acceptable

[a] Received from Orsanco EWODS.

[b] Based on 99% confidence interval.

TABLE 28. USEPA PERFORMANCE EVALUATION STANDARDS[a], NOVEMBER, 1979

Parameter	True Value (µg/l)	Reported Value (µg/l)	Acceptance Limits[b] (µg/l)	Performance Evaluation
Vial 1				
Chloroform	22.8	21.7	8.6 - 37.0	Acceptable
Bromodichloromethane	2.4	2.7	1.2 - 3.6	Acceptable
Dibromochloromethane	2.1	1.5	1.6 - 2.6	Not Acceptable
Bromoform	2.8	2.9	2.0 - 3.6	Acceptable
Total Trihalomethane	30.1	28.8	14.6 - 45.6	Acceptable
1,2-Dichloroethane	2.1	1.7	1.0 - 3.2	Acceptable
1,1,1-Trichloroethane	1.7	1.3	0.7 - 2.7	Acceptable
Carbon Tetrachloride	4.2	3.5	1.5 - 6.9	Acceptable
Trichloroethylene	1.9	1.6	0.7 - 3.1	Acceptable
Tetrachloroethylene	1.8	1.7	0.2 - 3.2	Acceptable
Vial 2				
Chloroform	91.3	90.8	34.2 - 148.4	Acceptable
Bromodichloromethane	23.8	25.9	2.2 - 45.4	Acceptable
Dibromochloromethane	10.3	8.4	6.4 - 14.2	Acceptable
Bromoform	11.4	11.0	8.4 - 14.4	Acceptable
Total Trihalomethane	136.8	136.1	72.7 - 200.9	Acceptable
1,2-Dichloroethane	17.3	16.2	6.4 - 28.2	Acceptable
1,1,1-Trichloroethane				
Carbon Tetrachloride	16.8	11.3	10.1 - 23.5	Acceptable
Trichloroethylene				
Tetrachloroethylene				

[a] Received from Orsanco EWODS.

[b] Based on 99% confidence interval.

TABLE 29. USEPA PERFORMANCE EVALUATION STANDARDS[a], JUNE, 1980

Parameter	True Value (µg/l)	Reported Value (µg/l)	Acceptance Limits[b] (µg/l)	Performance Evaluation
Vial 1				
Chloroform	11.0	10.6	5.0 - 17.0	Acceptable
Bromodichloromethane	1.7	1.4	0.2 - 3.2	Acceptable
Dibromochloromethane	2.4	2.3	1.3 - 3.5	Acceptable
Bromoform	2.8	2.2	1.5 - 4.1	Acceptable
Total Trihalomethane	17.9	16.5	10.0 - 25.8	Acceptable
1,2-Dichloroethane	1.5	1.2	0.5 - 2.5	Acceptable
1,1,1-Trichloroethane	1.2	0.8	0.6 - 1.8	Acceptable
Carbon Tetrachloride	2.3	1.8	1.0 - 3.6	Acceptable
Trichloroethylene	2.6	2.2	1.9 - 3.3	Acceptable
Tetrachloroethylene	1.1	0.9	0.8 - 1.4	Acceptable
Vial 2				
Chloroform	45.6	48.2	27.2 - 64.0	Acceptable
Bromodichloromethane	8.6	9.3	4.3 - 12.9	Acceptable
Dibromochloromethane	12.0	12.6	9.0 - 15.0	Acceptable
Bromoform	10.4	13.1	2.6 - 18.2	Acceptable
Total Trihalomethane	76.6	83.2	44.2 - 109.0	Acceptable
1,2-Dichloroethane	20.0	15.7	0 - 43.4	Acceptable
1,1,1-Trichloroethane	14.0	9.6	6.3 - 21.6	Acceptable
Carbon Tetrachloride	9.4	6.0	5.3 - 13.5	Acceptable
Trichloroethylene	13.0	9.6	8.9 - 17.1	Acceptable
Tetrachloroethylene	5.6	5.6	3.9 - 7.3	Acceptable

[a] Received from Orsanco EWODS.

[b] Based on 99% confidence interval.

TABLE 30. USEPA PERFORMANCE EVALUATION STANDARDS[a], FEBRUARY, 1981

Parameter	True Value (µg/l)	Reported Value (µg/l)	Acceptance Limits[b] (µg/l)	Performance Evaluation
Vial 1				
Chloroform	11.0	9.6	6.8 - 15.2	Acceptable
Bromodichloromethane	1.7	1.4	0.9 - 2.5	Acceptable
Dibromochloromethane	2.4	2.4	1.8 - 3.0	Acceptable
Bromoform	2.8	2.1	1.2 - 4.4	Acceptable
Total Trihalomethane	17.9	15.5	13.6 - 22.2	Acceptable
1,2-Dichloroethane	1.5	1.3	0 - 3.8	Acceptable
1,1,1-Trichloroethane	1.1	0.8	0.3 - 1.9	Acceptable
Carbon Tetrachloride	2.3	2.3	1.3 - 3.3	Acceptable
Trichloroethylene	2.6	2.6	1.6 - 3.6	Acceptable
Tetrachloroethylene	1.1	0.9	0.5 - 1.7	Acceptable
Vial 2				
Chloroform	45.6	47.8	31.1 - 60.1	Acceptable
Bromodichloromethane	8.6	10.5	5.9 - 11.3	Acceptable
Dibromochloromethane	12.0	14.2	6.2 - 17.7	Acceptable
Bromoform	10.4	11.5	3.2 - 17.6	Acceptable
Total Trihalomethane	76.6	84.0	62.5 - 90.7	Acceptable
1,2-Dichloroethane	20.0	16.5	11.6 - 28.4	Acceptable
1,1,1-Trichloroethane	14.0	9.0	7.8 - 20.2	Acceptable
Carbon Tetrachloride	9.4	7.2	6.3 - 12.5	Acceptable
Trichloroethylene	13.0	10.4	0 - 38.1	Acceptable
Tetrachloroethylene	5.6	5.1	4.0 - 7.2	Acceptable

[a] Received from Orsanco EWODS.

[b] Based on 99% confidence interval.

TABLE 31. AVERAGE PERCENT RELATIVE DEVIATION OF PURGEABLE NON-HALOGENATEDS[a]

Duplicate Samples[b]

Parameter	Average Percent Relative Deviation
Hexane	8.3[c]
Benzene	2.4
Toluene	ND[d]
Ethyl Benzene	0[c]
o-Xylene	ND
Tetralin	ND

Replicate Samples[b]

Parameter	Average Percent Relative Deviation
Hexane	ND
Benzene	6.3
Toluene	ND
Ethyl Benzene	ND
o-Xylene	ND
Tetralin	ND

[a] Analysis performed by Cincinnati Water Works.
[b] Based on samples with concentrations equal to or greater than 0.4 µg/l.
[c] Based only on one value.
[d] Not detected, values were less than 0.4 µg/l.

at the end of the sample series and compared to the standardization run. The average percent relative deviation was 2.57 which is well within acceptable limits.

The results from the USEPA Performance Evaluation Study WP005 can be found in Table 32. From the table, it can be seen that vial 1's result was acceptable while vial 2's result was not acceptable. Upon investigation of the result from vial 2, it was observed that although the 150 µl of persulfate reagent was sufficient for the normal concentration range observed, it was not sufficient for the concentration level in vial 2. Further investigation indicated that 150 µl of persulfate reagent was sufficient for TOC values less than 4.0 mg/l. The method of analysis was modified so that any sample with a TOC value greater than 3.0 mg/l would be rerun using 300 µl of persulfate reagent. This provides sufficient reagent for TOC values up to 10.0 mg/l.

TABLE 32. TOC RESULTS FROM USEPA PERFORMANCE EVALUATION STANDARDS WS005

	TOC Concentration (mg/l)	
	Reported Value	True Value
Vial 1	3.2	3.2
Vial 2	8.6	107

SECTION 6

RESULTS AND DISCUSSION

Discussion of the observations and recorded data resulting from the operation of both pilot and full-scale GAC systems as well as the analytical results of the many areas being investigated are presented in segments addressed as specific objectives consistent with the goals of the grant study. The format will follow the chronology of the three phase program.

PHASE 1. FULL-SCALE GAC FILTERS

Objective 1: To Compare the Relative Performance of Various Depths and Types of GAC

Three sand filters (19A, 21A and 23A) were converted to GAC filters as detailed in Section 4 with provisions for sampling at various depths as indicated in Figure 15. The combination of sample probe locations and differing GAC beds afforded the opportunity to evaluate the effect of varied contact times and effectiveness of different GAC types.

Effect of Various Contact Times--

The GAC filters were designed so that samples could be collected at various depths. Figure 15 shows the three GAC filters and their respective intermediate sample depths. A comparison of the results from these intermediate sample points would show the effects of longer contact time on removing organics from the water. It would also be possible to watch the progression of exhaustion through the bed.

Sample collection from the intermediate depths was accomplished by placing stainless steel auger-type sample probes at the specified depths in the filters. A pump was then used to draw the sample from the desired depth for collection.

Collection of these intermediate sample points proved to be difficult. Air had a tendency to collect in pockets around the sample probes which made priming of the pump and sample line very difficult. In order to release the bound air, the sample probe, or auger, was rotated in place. Rotating the sample probe did not always solve the problem of sample collection.

Examination of the breakthrough curves showed inconsistent results from what would have been expected when comparing similar bed depths. Figure 16 shows the THMMAX breakthrough curves for 19AE and 21A2 and is an example of

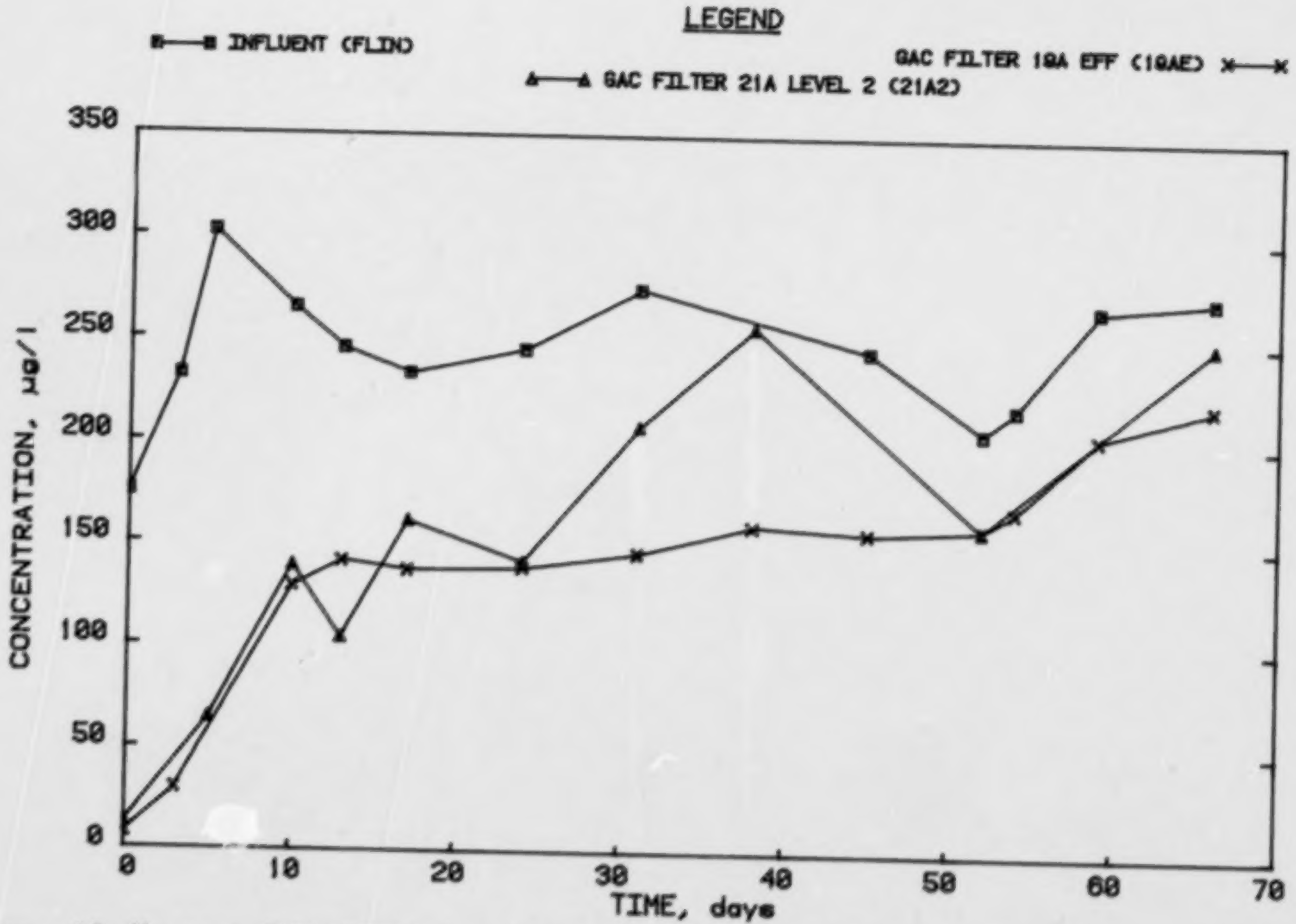


Figure 16. Maximum THM (MTTT) breakthrough curves for GAC Filters 21A level 2 and 19A effluent, Phase 1-0.

the inconsistency observed. These two locations represented the same EBCT and should, therefore, have identical curves. For the most part, the two locations do parallel each other. However, on rundays 31 and 38, the intermediate sample point (21A2) does not match 19AE. The concentrations for 21A2 on these two days approached and almost equaled the influent (FLIN) THMMAX concentration. This inconsistency might have been due to the sample collection technique since the rotation of the sample probe may have permitted the channeling of the influent, (FLIN) down the sample probe. This short circuiting would have resulted in little if any contact time with the GAC, resulting in a higher THMMAX concentration.

Interpretation of the data from the intermediate sample points was severely restricted because of this potential sample collection problem. Examination of the breakthrough curves through the GAC filters does show that longer contact time provides additional removal of organics. However, determination of the benefits of this longer contact time cannot be made with any real confidence by using the intermediate sample depths.

It is still possible to address the effect of contact time by comparing the effluents from GAC Filters 19A and 21A which had 4.5 and 7.5 minutes EBCT, respectively. Before comparing these two GAC filters, some clarification of data interpretation is first necessary.

During Phase 1, a review of the data revealed that the concentrations from a large number of backlogged THM analyses were excessively high. This covered the period from February 14, 1978 to May 15, 1978. Subsequent investigation revealed that insufficient quench agent, sodium sulfite, was being used. Therefore, free chlorine was available for further reaction with THM precursors and additional THMs formed. Unfortunately, this invalidates much of the data collected during the early stage of the GAC filters' life. The various types of THM analyses were affected as follows:

1. INSTTHM: Invalid, except for the GAC filter samples where the chlorine had been adsorbed by the GAC.

2. THMMAX: Valid, little additional chlorine-precursor reaction occurred after the one-week reaction time used for forming the THMMAX.

3. THMFP: Invalid, except for the GAC filter samples. The THMFP calculation involved the subtraction of INSTTHM from THMMAX.

4. THMSIMDIST: Invalid, additional chlorine-precursor reaction was possible even after the one-week reaction time used for the THMSIMDIST method.

The determination of the effect of different contact times between the effluents from GAC Filters 19A and 21A was still possible even with the limitations placed on data use. Breakthrough curves for TOC and THMMAX can be found in Figures 17 and 18, respectively. Figure 19 shows INSTTHM concentrations for 19AE and 21AE. From these figures, it can readily be seen that longer contact time provided improved effluent water quality. Selection

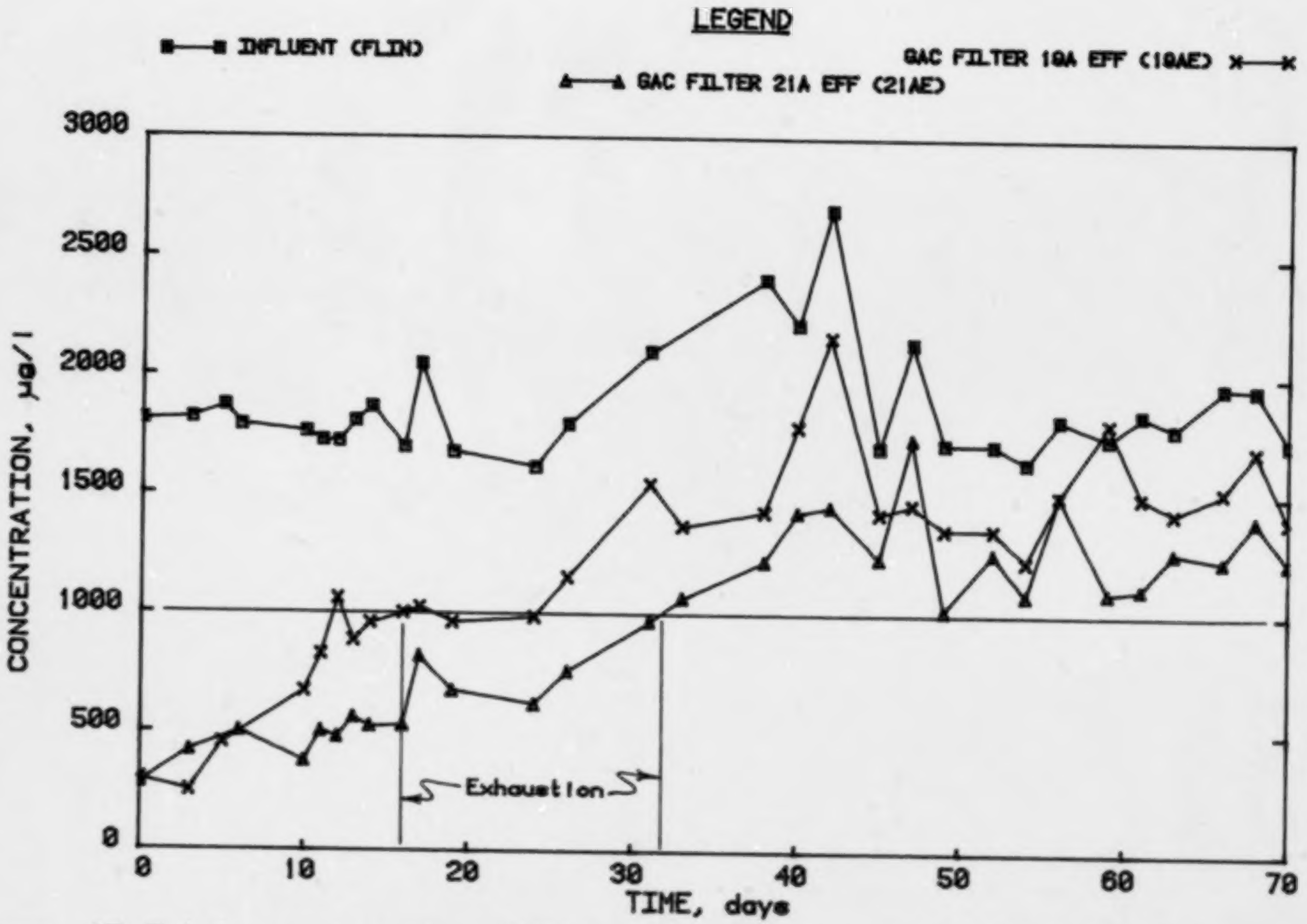


Figure 17. Total organic carbon (TOC) breakthrough curves for GAC Filter 19A and 21A effluents, Phase 1-0.

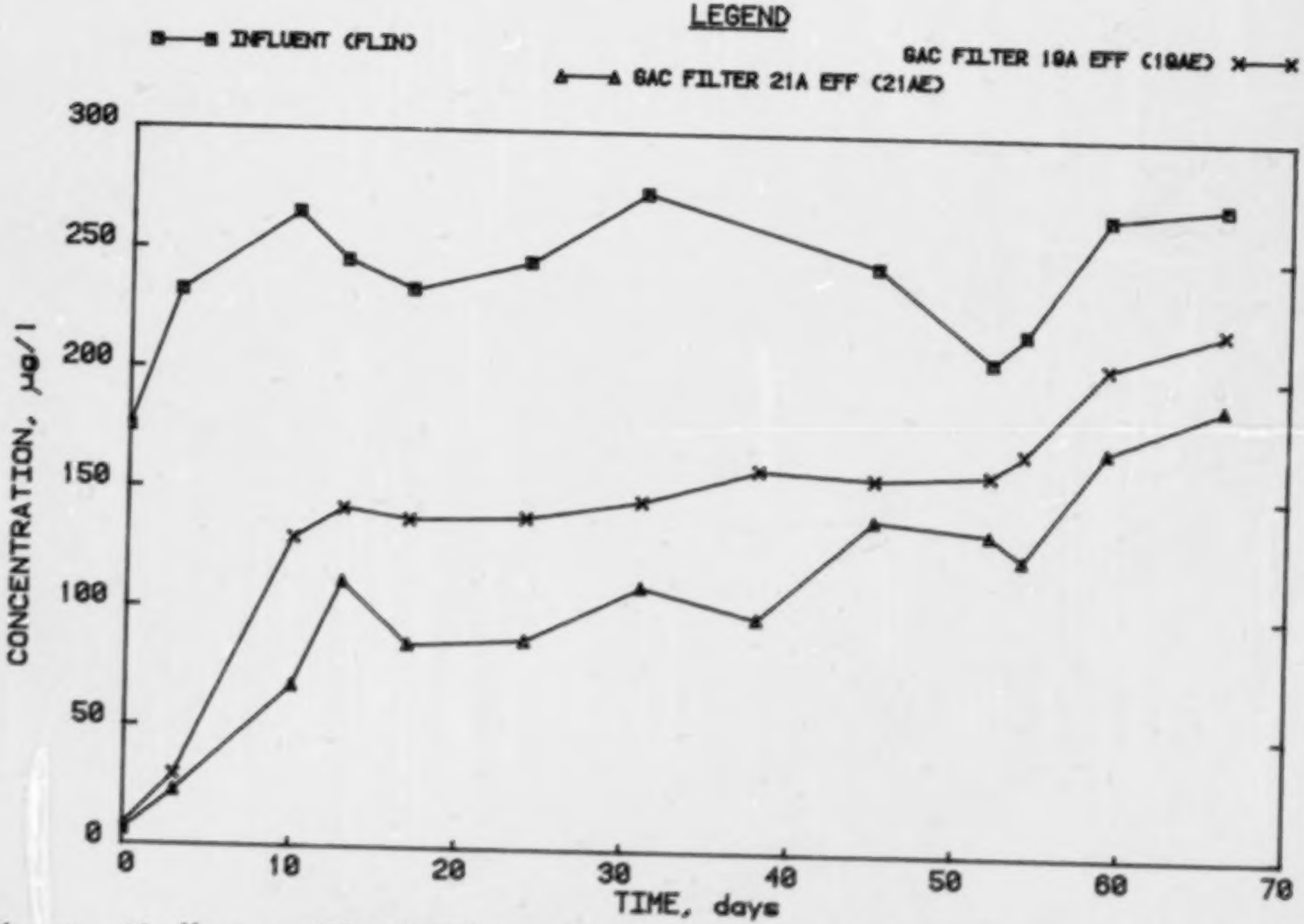


Figure 18. Maximum THM (MTTT) breakthrough curves for GAC Filter 19A and 21A effluents, Phase 1-0.

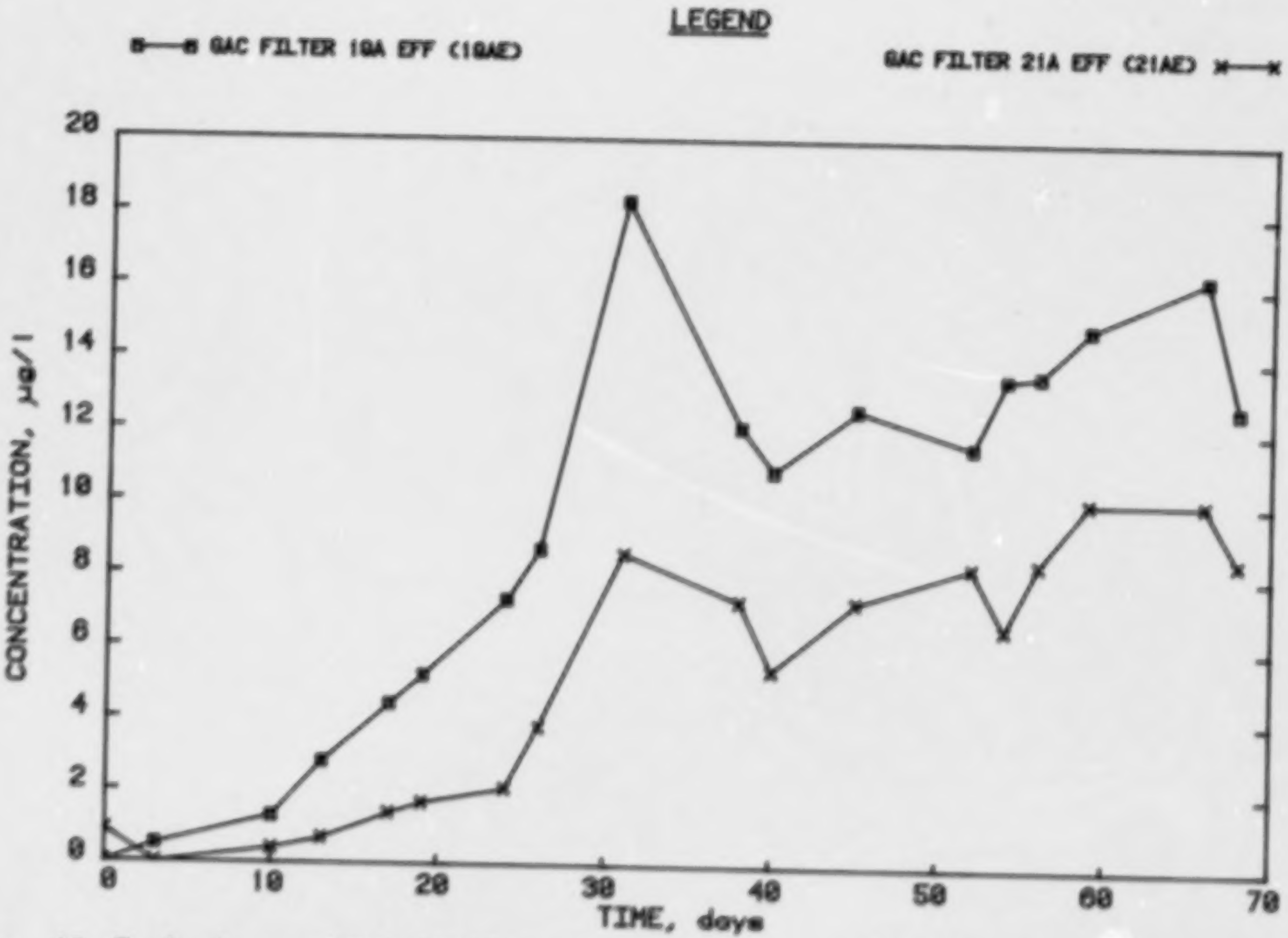


Figure 10. Instantaneous THM (ITTT) concentration curves for GAC Filter 10A and 21A effluents, Phase 1-0.

of a treatment goal of 1,000 µg/l for TOC in the effluent (as represented by the intersection of the treatment goal line and the breakthrough curve when the average of any three-week set exceeded the goal) permitted further evaluation of contact time. This effluent requirement resulted in an operating service time of about 32 days for GAC Filter 21A and 16 days for GAC Filter 19A. Therefore, increasing the EBCT by a factor of 1.7 resulted in an increase in the operating service time by a factor of 2.0.

The purgeable halogenated minimum, maximum and average results can be found in Table 33. It is felt that the dichloromethane results represented an artifact due to the use of dichloromethane in the laboratory. The influent concentrations were very low and for most samples approached the lower limits of the detector (approximately 0.1 µg/l). Both GAC filters performed similarly when they received an elevated 1 to 2 µg/l dose of carbon tetrachloride, 1,1,1-trichloroethane, chlorobenzene and o-dichlorobenzene. Except for 1,1,1-trichloroethane, they were very effective in the removal of these compounds.

Purgeable non-halogenated samples were collected but very few analyses were performed due to analytical problems encountered with the method.

The above data indicates that longer EBCT in GAC filters resulted in an increase in the operating service time. However, the optimum EBCT for GAC filters was not determined due to the limited number of sample points and minimal bed depth.

Comparison of Different Grades of Bituminous-Based GAC--

As previously described, GAC Filter 21A contained 76.2 cm (30 in) of 12 x 40 WVG and GAC Filter 23A, contained 76.2 cm (30 in) of 20 x 50 WVW GAC. This configuration permitted the comparison of two different grades of bituminous-based GAC.

The TOC breakthrough curves for 21A and 23A can be found in Figure 20. The breakthrough curves show 21A and 23A to be very similar for the first 20 days, after which 21A outperformed 23A. A treatment goal of 1,000 µg/l for TOC in the effluent was again used for further evaluation. This effluent requirement would result in an operating service time of about 32 days for 21A and 24 days for 23A. Based on this criteria, 21A was only slightly superior to 23A.

The THMMAX breakthrough curves for 21A and 23A can be found in Figure 21. From the figure, it is apparent that 21A outperformed 23A. For further evaluation, an exhaustion criterion of 100 µg/l THMMAX, similar to the level specified in the Safe Drinking Water Act[7], in the effluent (as represented by the intersection of the treatment goal line and the breakthrough curve when the average of any three-week set exceeds the goal) was selected. This exhaustion criterion would have resulted in an operating service time of about seven days for GAC Filter 23A and 28 days for GAC Filter 21A. Based on this exhaustion criteria, the configuration of 21A was superior.

TABLE 33. PURGEABLE HALOGENATED ORGANICS FOR GAC FILTERS 19A AND 21A, PHASE 1-0

	Influent			19A			21A		
Parameter	Min Value (µg/l)	Max Value (µg/l)	Avg Value (µg/l)	Min Value (µg/l)	Max Value (µg/l)	Avg Value (µg/l)	Min Value (µg/l)	Max Value (µg/l)	Avg Value (µg/l)
Carbon tetrachloride	a	1.7	0.1	a	0.2	0.0	a	0.2	0.0
1,2-Dichloroethane	a	0.7	0.0	a	a	a	a	a	a
1,1,1-Trichloroethane	a	1.5	0.1	a	1.2	0.1	a	1.0	0.1
Dichloromethane	a	21.9	0.8	a	6.0	0.6	a	5.1	0.5
Tetrachloroethylene	a	0.2	0.1	a	0.2	0.0	a	0.2	0.0
Trichloroethene	a	0.4	0.1	a	0.2	0.0	a	0.2	0.0
Chlorobenzene	a	2.2	0.1	a	0.2	0.0	a	0.2	0.0
0-Dichlorobenzene	a	1.3	0.2	a	0.2	0.0	a	0.2	0.0

[a] Not Detected (0.1 µg/l)

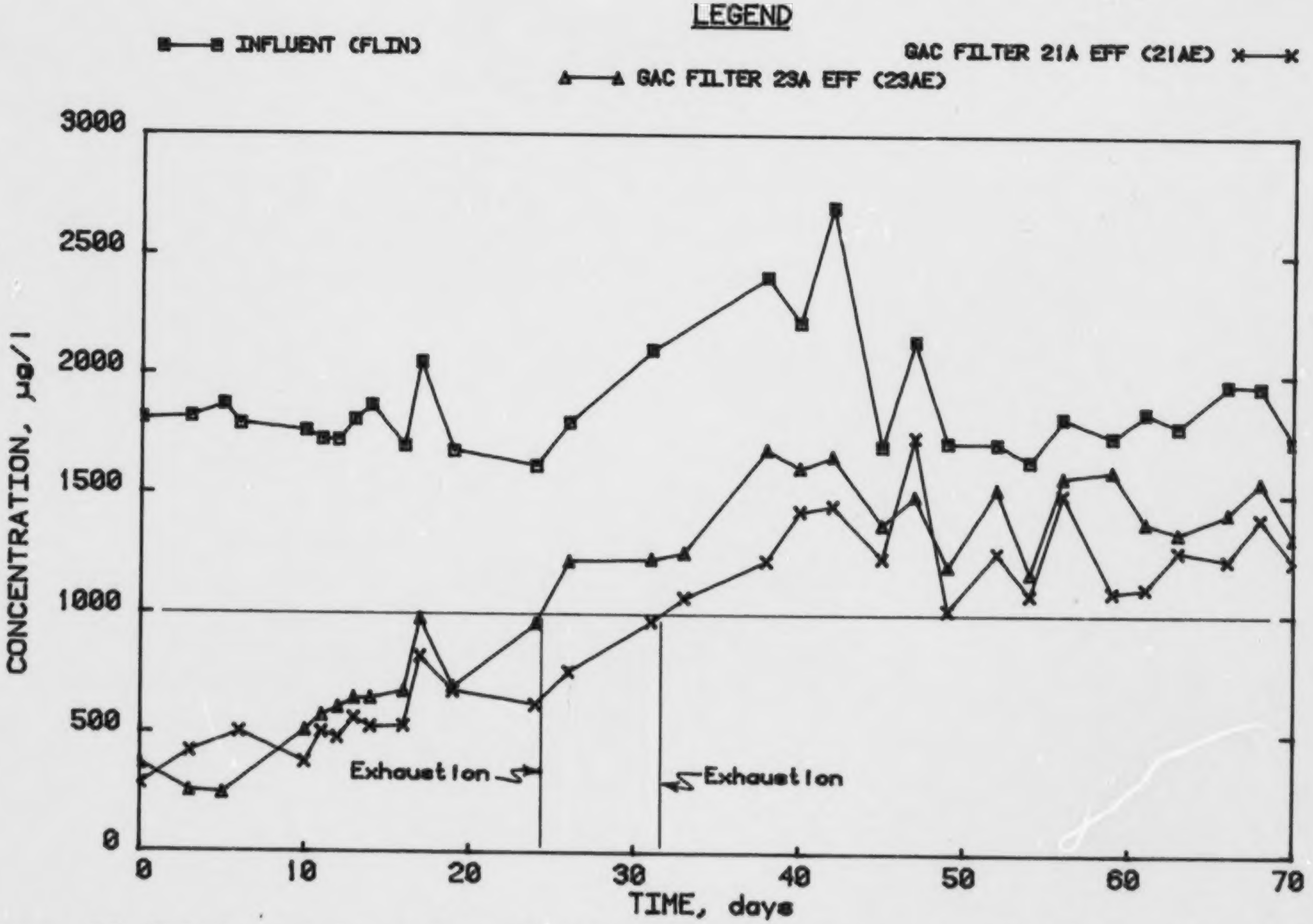


Figure 20. Total organic carbon (TOC) breakthrough curves for GAC Filter 21A and 23A effluents, Phase 1-0.

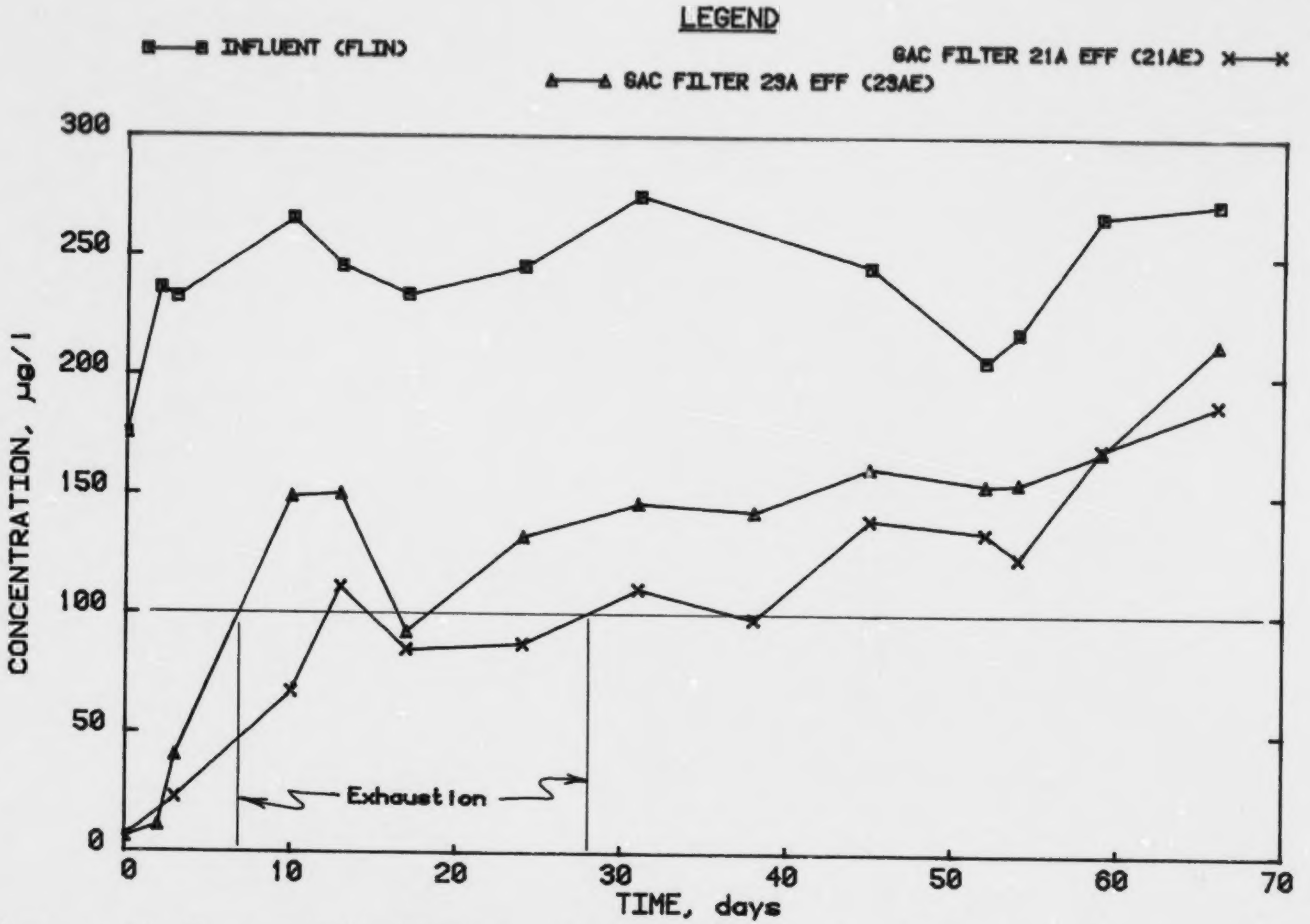


Figure 21. Maximum THM (MTTT) breakthrough curves for GAC Filter 21A and 23A effluents, Phase 1-0.

The INSTTHM concentration in 21A and 23A effluents can be found in Figure 22. The effluents from both GAC filters were almost identical. However, the highest INSTTHM concentration observed was approximately 10 µg/l. This was a very low concentration probably due to low temperature water. It is important to note that comparison of performance should always take concentration into account.

The purgeable halogenated organics minimum, maximum and average results for influent, 21A and 23A can be found in Table 34. As before, the dichloromethane results were likely artifacts. The influent concentrations were very low and, for the most part, approached the lower limit of the detector. The performance of 21A and 23A were very similar based on very low influent concentrations.

Purgeable non-halogenated samples were collected but very few analyzed due to analytical problems encountered with the method.

One set of base-neutral extractables was analyzed. The only reported organics were phthalate plasticizers that seem to be laboratory artifacts, since often blank concentrations were higher than those of the samples.

At the end of the run, 23A was found to have lost 34% of its GAC volume compared to only 14% for 21A. Due to the smaller particle size and weight of 23A GAC, utilization of backwash procedures acceptable for 12 x 40 GAC filters likely resulted in the excessive losses for 20 x 50 GAC contained in 23A. Modifications to the procedure were initiated to minimize this loss but backwash velocities sufficient to remove floc were still likely great enough to continue the higher GAC attrition through the rest of the phase. Given that shorter 23A filter runs occurred throughout this phase (discussed in Objective 2), it is apparent that floc was not completely flushed out at the reduced backwash rates.

In summary, the combined results from organic evaluations and backwashing experiences tend to indicate that 20 x 50 GAC would not function properly in our plant. Rather, the 12 x 40 GAC would be preferred.

Objective 2. To Compare the Relative Performance of Sand vs. GAC as a Filter Media for Particulate Matter

GAC, as a filter media, performed the filtration function as well as, or better than sand. Table 35 shows that the GAC filters with 12 x 40 GAC consistently gave longer service between washes than the plant average, including sand and GAC filters. It is possible that the plant average could have been slightly higher than shown since sand filters were washed after attaining 1.8 m (6 ft) of head loss or 60 hours of operation whichever occurred first, while the GAC filters were washed on head loss alone.

During the period of the study, filter runs became increasingly longer. The 76.2 cm (30 in), 12 x 40 GAC bed also experienced increased run times, but at a rate less than the plant average. The run time of the 45.7 cm (18 in), 12 x 40 bed tended to be stable, but still performed better than

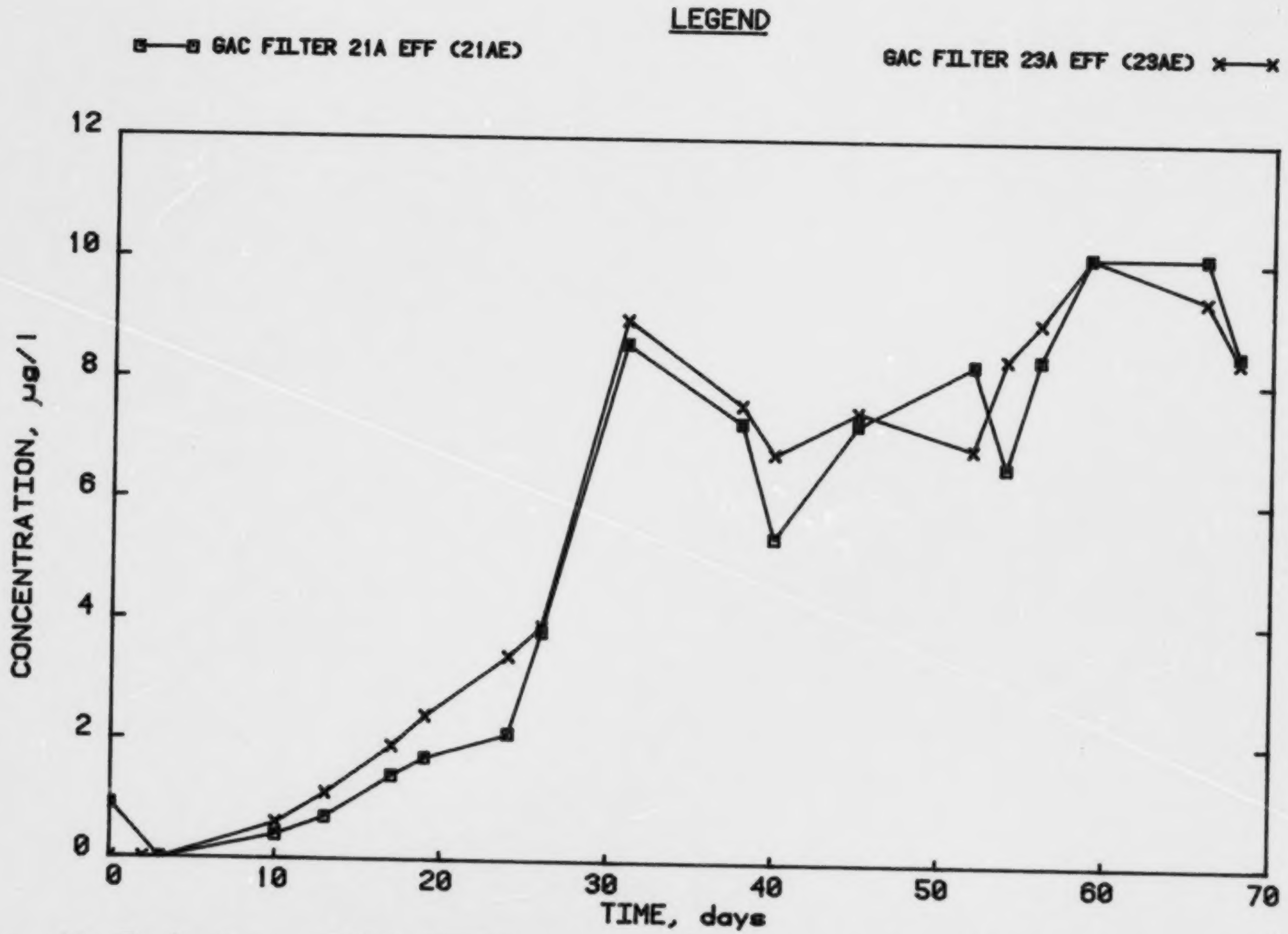


Figure 22. Instantaneous THM (ITTT) concentration curves for GAC Filter 21A and 23A effluents, Phase 1-0.

TABLE 34. PURGFABLE HALOGENATED ORGANICS FOR GAC FILTERS 21A AND 23A, PHASE 1-0

Parameter	Influent			21A			23A		
	Min Value (µg/l)	Max Value (µg/l)	Avg Value (µg/l)	Min Value (µg/l)	Max Value (µg/l)	Avg Value (µg/l)	Min Value (µg/l)	Max Value (µg/l)	Avg Value (µg/l)
Carbon tetrachloride	a	1.7	0.1	a	0.2	0.0	a	0.2	0.0
1,2-Dichloroethane	a	0.7	0.0	a	a	a	a	a	a
1,1,1-Trichloroethane	a	1.5	0.1	a	1.0	0.1	a	0.9	0.0
Dichloromethane	a	21.9	0.6	a	5.1	0.5	a	4.9	0.7
Tetrachloroethylene	a	0.2	0.1	a	0.2	0.0	a	a	a
Trichloroethene	a	0.4	0.1	a	0.2	0.0	a	0.4	0.0
Chlorobenzene	a	2.2	0.1	a	0.2	0.0	a	0.2	0.0
0-Dichlorobenzene	a	1.3	0.1	a	0.2	0.0	a	0.2	0.0

[a] Not Detected (0.1 µg/l)

TABLE 35. COMPARISON OF FILTER RUN BETWEEN GAC FILTERS AND PLANT AVERAGE

Filter	Yearly Average Hours Between Washes 1978	 1979	 1980
19A	61.9	58.7	59.0
21A	48.0	58.5	64.7
23A	21.0	36.8	31.8
Total Plant[a]	27.5	38.9	45.8

[a] Includes GAC filters.

the plant average. This increase in the length of filter runs may be attributed to the improved river quality. Except for three brief episodes with a slight rise in turbidity (all less than 1.0 NTU) on the 45.7 cm (18 in) bed early in the run, the effluent clarity of GAC filters was as good as that of the sand filters.

At no time were the length of filter runs for the 20 x 50 GAC filter as long as the plant average, some runs being as short as 6.4 hours. One likely explanation was that the backwash rates which were reduced to minimize GAC losses did not completely remove filterable solids. During the winter months, when water temperature ranged below 2°C (35°F), air binding further shortened filter runs. The 12 x 40 GAC filters also had a tendency to air bind more than sand filters but not as pronounced as the 20 x 50 GAC.

To eliminate the effect of the inclusion of the GAC filters in establishing the plant average as well as possible suppression due to the 60 hour maximum run on a sand filter, direct comparison of sand filters was made with GAC Filters (Table 36). The week of August 9 through 15, 1981 was selected because the sand filter runs were consistently below 60 hours. The results are fairly conclusive that the service life of the GAC filters was approximately 150% of that for the sand filters.

TABLE 36. COMPARISON OF FILTER RUN TIMES DURING TYPICAL PERIOD WHEN SAND FILTER RUNS WERE LESS THAN 60 HOURS[a]

	Sand Filters	GAC Filters
Number of Runs	141	8
Avg. Time in Service, Hours	29.2	45.0

[a] Week of August 9 through 15, 1981.

From the foregoing, it is evident that while GAC was generally effective as a filter media, not all grades and types are equal in performance. Specifically, the 20 x 50 GAC would require more frequent backwashes during extended periods of increased turbidity and extremely cold weather.

Further, the dual-media [30.5 cm (12 in) sand, 45.7 cm (18 in) GAC] GAC filter would be less practical than the full-depth GAC bed, since lower backwash rates dictated by the use of GAC may not expand and clean the sand portion of the bed. As an adsorption agent, the reduced contact time and reduced bed volume would greatly reduce the bed life.

PHASE 2. PILOT GAC FILTERS AND PILOT CONTACTORS

Objective 3. To Compare the Relative Performance of Virgin and Regenerated GAC Filters

In this aspect of Phase 2, bituminous-based GAC was utilized as a direct filtration media in the 7.6 cm (3 in) pilot columns described in Section 4 and operated within the parameters set forth in Section 5. This comparison extended through two laboratory regeneration cycles.

Figures 23 through 26 show a comparison of virgin versus once-regenerated GAC for various parameters. This and the subsequent regeneration were performed by the Westvaco Corp. using a laboratory-scale, fluidized-bed regenerator at 1500°F. These figures indicate that the percent removals for TOC, INSTTHM, THMSIMDIST and THMFP were practically identical.

Figures 27 through 30 show a comparison of virgin versus twice-regenerated GAC for the same parameters. These figures again indicate that the percent removals for TOC, INSTTHM, THMSIMDIST and THMFP were practically identical.

Analyses performed included TOC, THMSIMDIST, INSTTHM, THMFP, non-THM purgeable halogenated, purgeable non-halogenated and base/neutral extractable compounds. Due to difficulties in obtaining consistent results from contract laboratories, data concerning the latter two classes of compounds do not provide for any useful evaluation. Purgeable halogenated compounds, other then THMs, were seldom seen in sufficient quantities to be useful.

Based on the data, there appears to be no appreciable effect on the GAC's adsorptive capabilities after two regeneration cycles.

Objective 4. To Compare the Relative Performance of Bituminous- and Lignite-Based GAC in Pilot Contactors

A description of the physical facilities used to evaluate this objective is contained in Section 4. Both pilot column systems contained essentially the same volume of GAC and received essentially the same influent water, loading rate and throughput over the same time frame (October 24, 1978 through May 31, 1979). It should be noted that during this time frame,

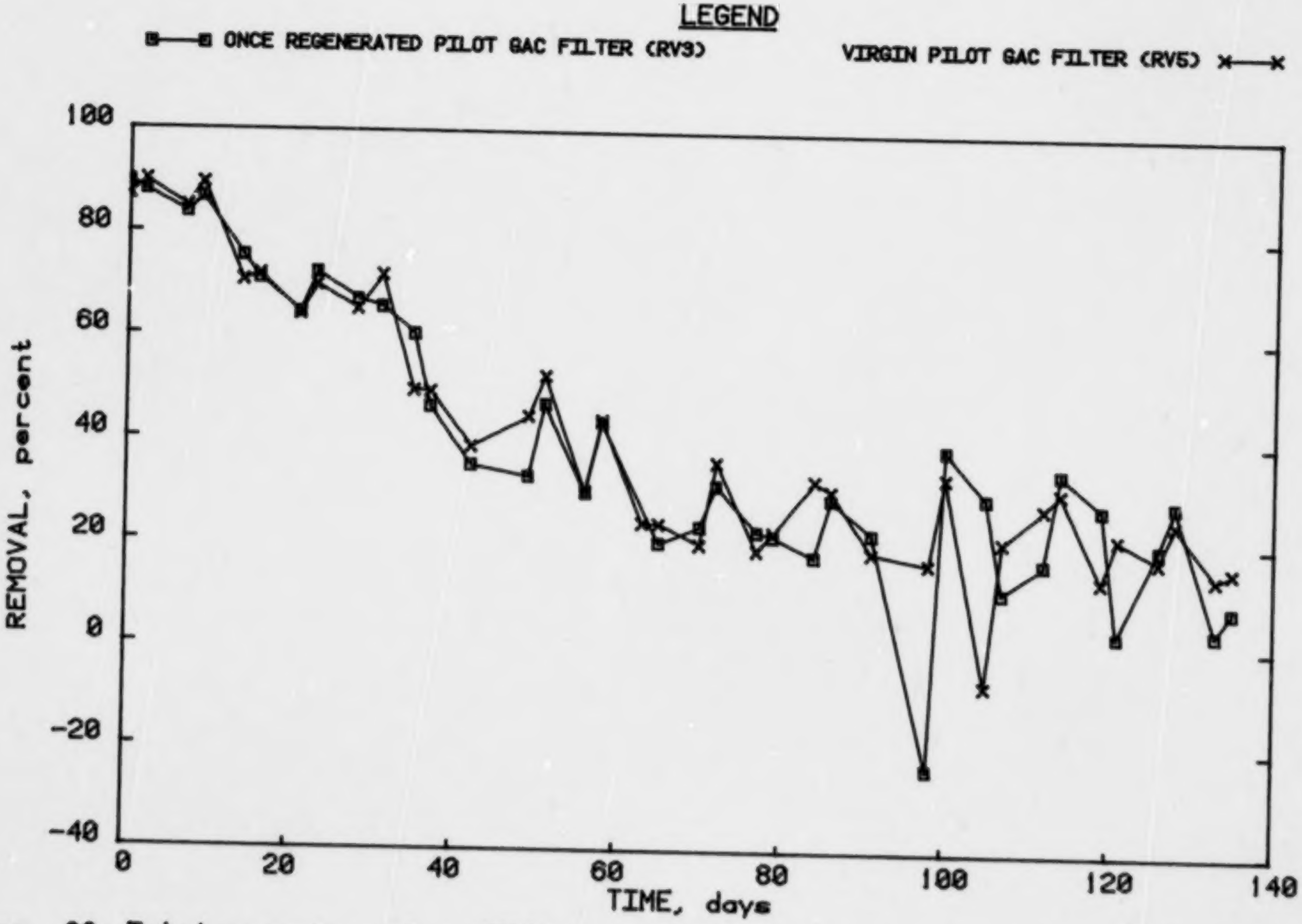


Figure 23. Total organic carbon (TOC) percent removal curves for virgin and once regenerated pilot GAC filter effluents, Phase 2-1.

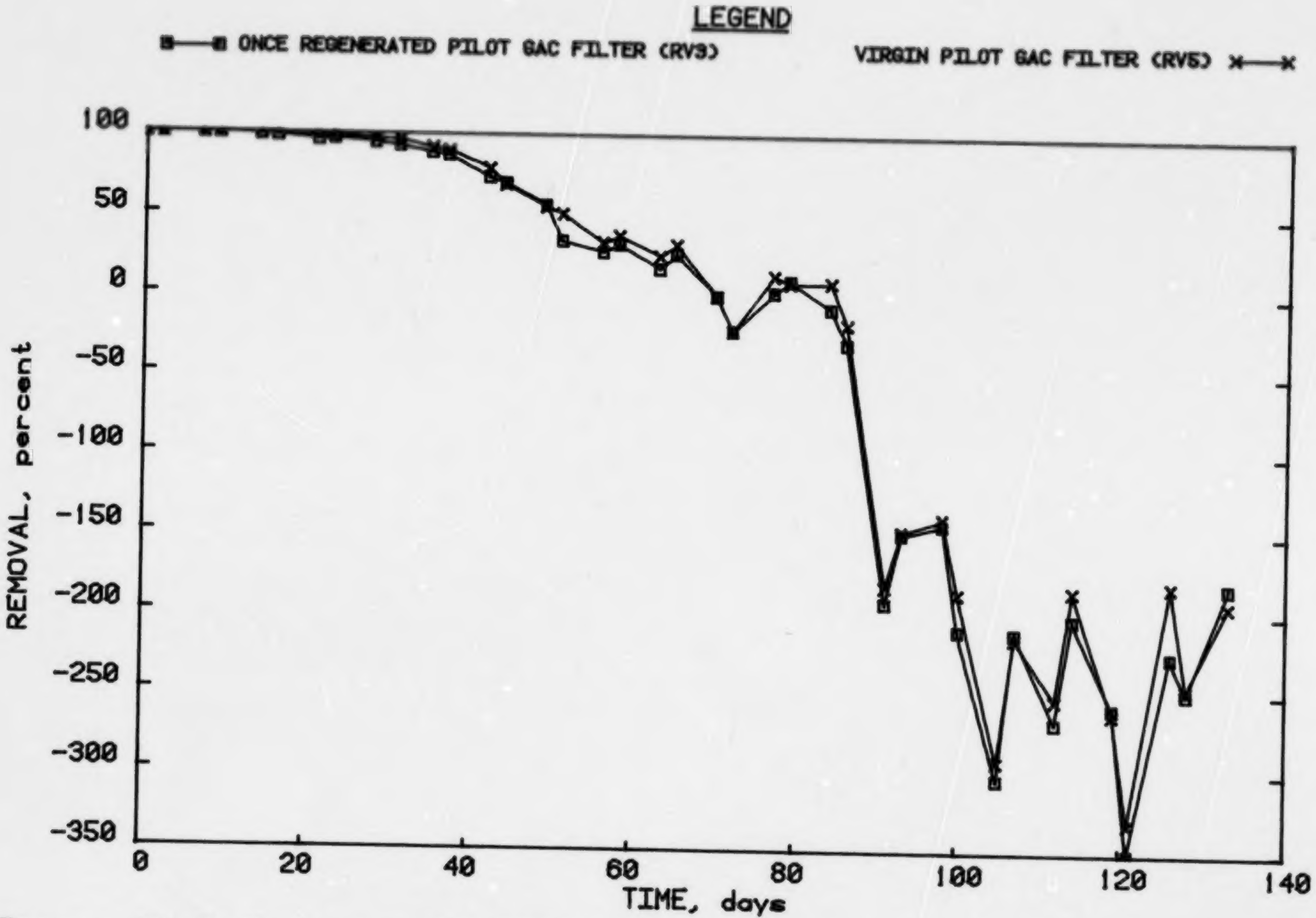


Figure 24. Instantaneous THM (ITTT) percent removal curves for virgin and once regenerated pilot GAC filter effluents, Phase 2-1.

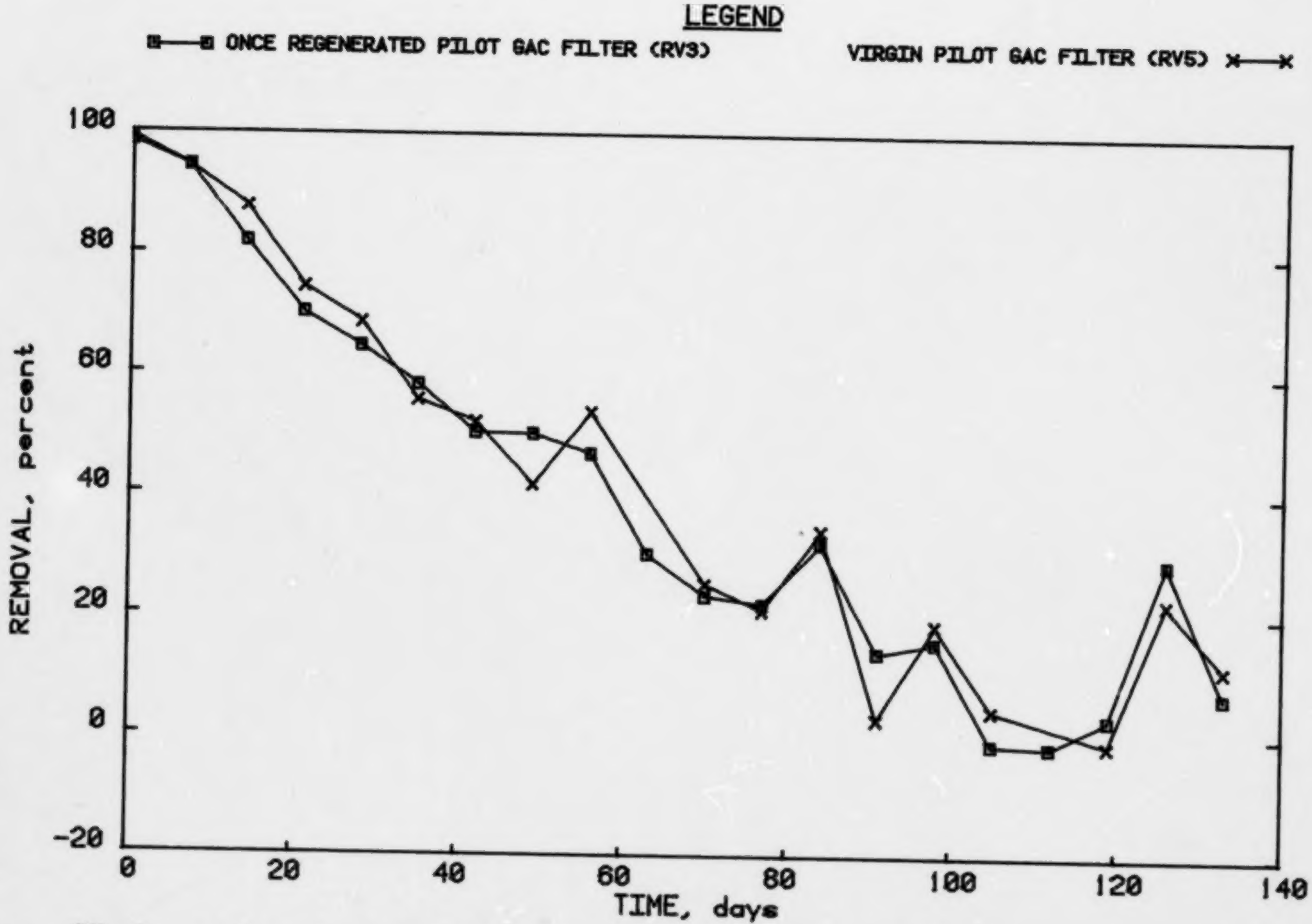


Figure 25. Seven-day simulated distribution syst. THM (STT7) percent removal curves for virgin and once regenerated pilot GAC filter effluents, Phase 2-1.

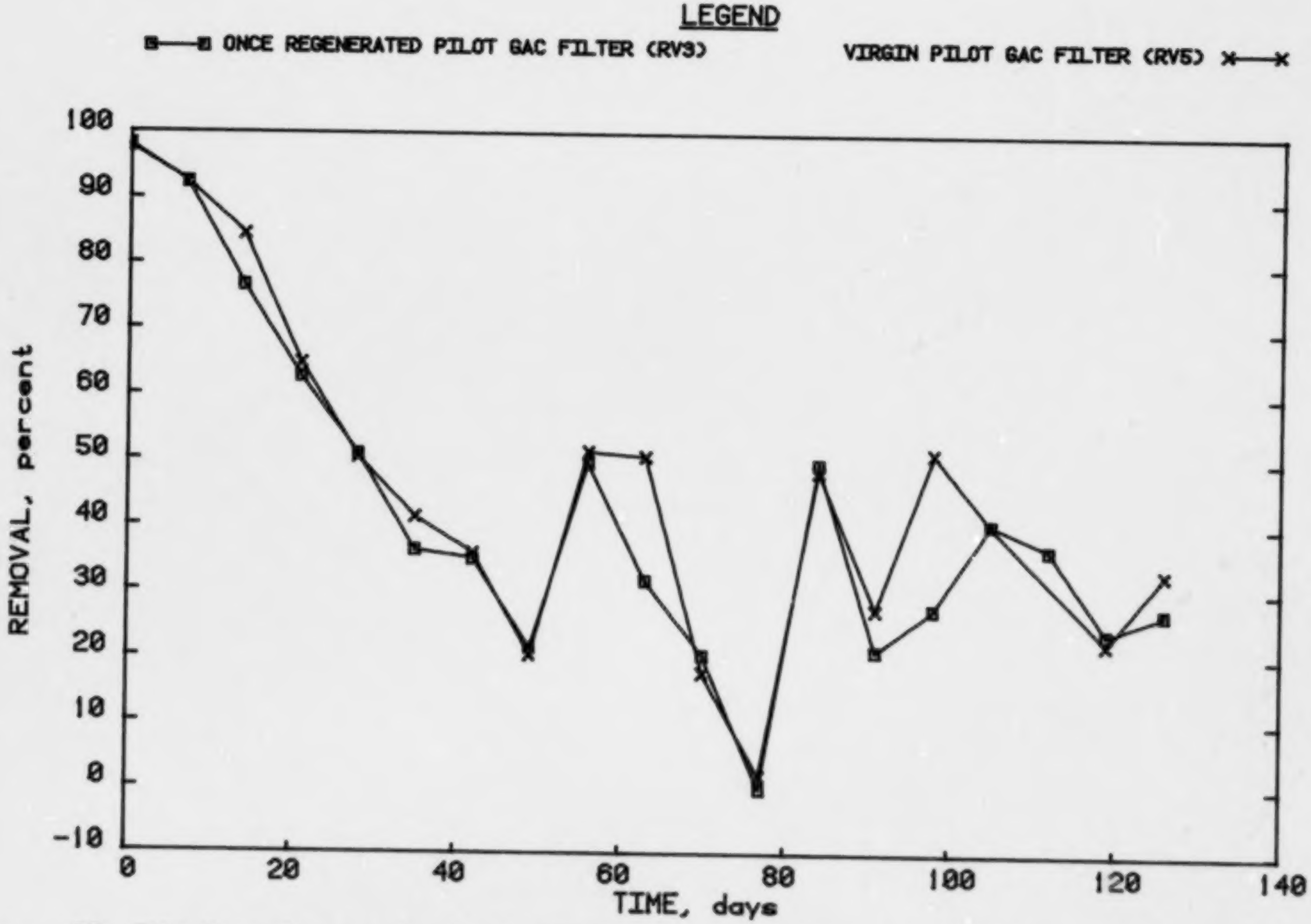


Figure 26. THM formation potential (FTTT) percent removal curves for virgin and once regenerated pilot GAC filter effluents, Phase 2-1.

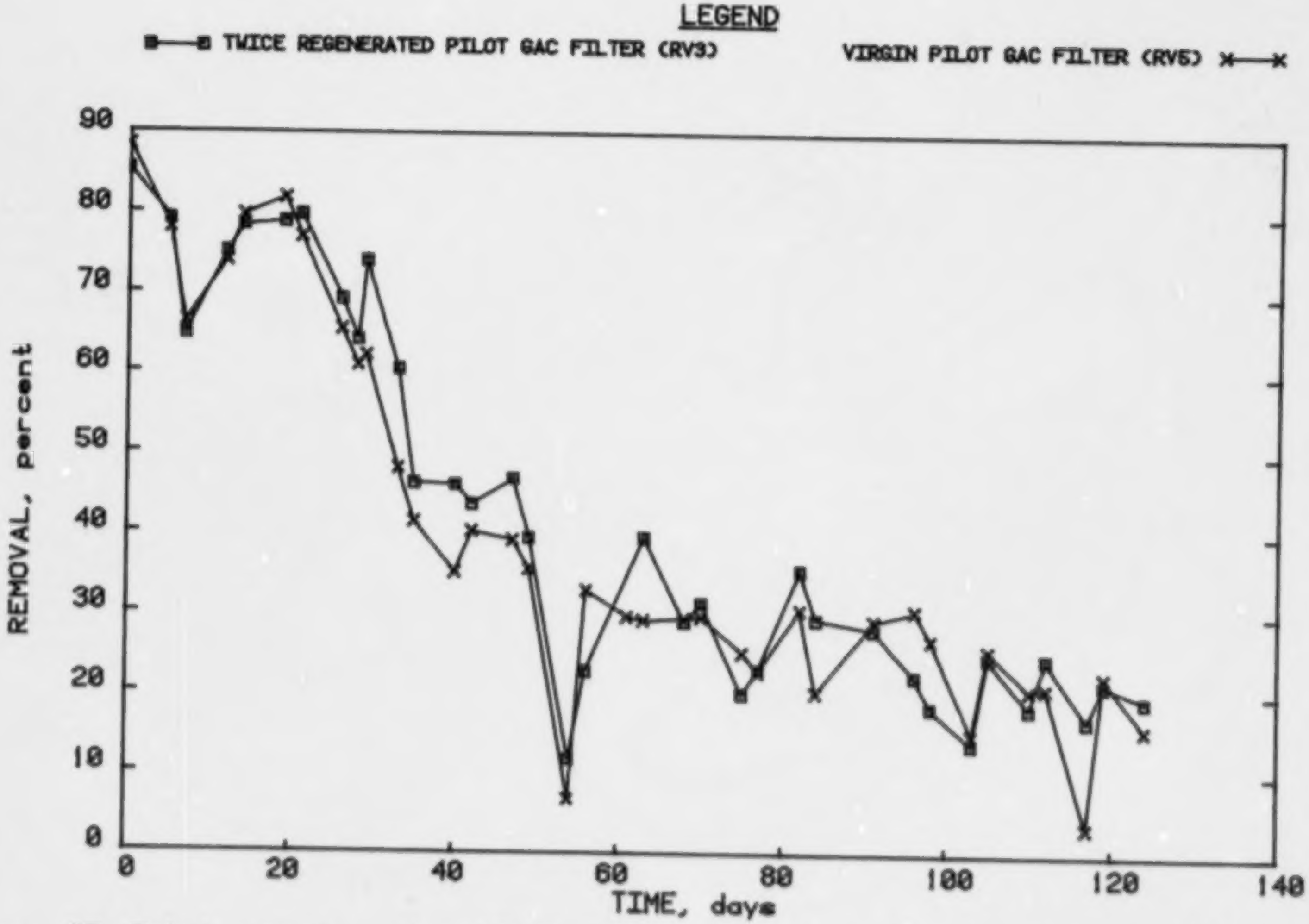


Figure 27. Total organic carbon (TOC) percent removal curves for virgin and twice regenerated pilot GAC filter effluents, Phase 2-2.

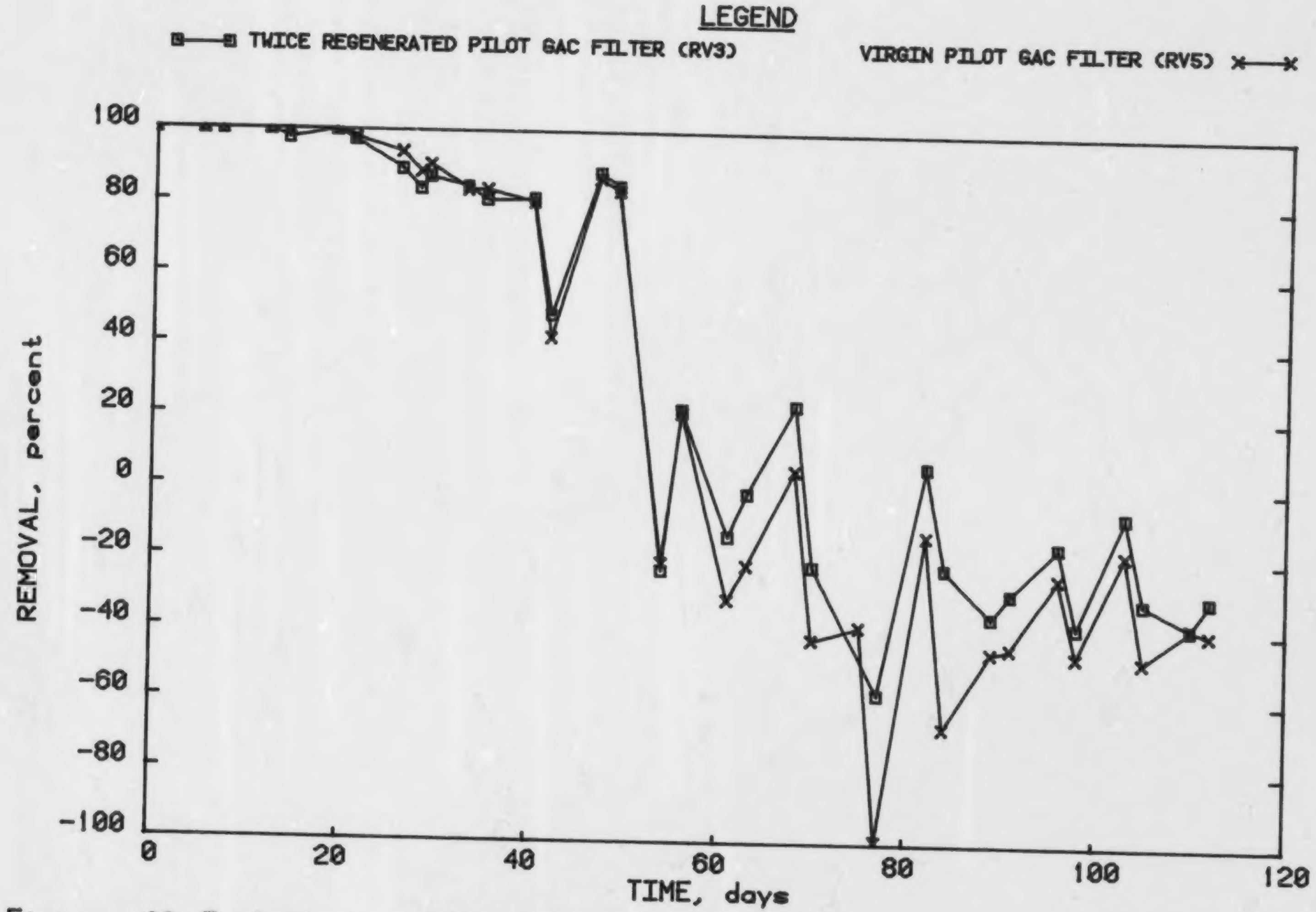


Figure 28. Instantaneous THM (ITTT) percent removal curves for virgin and twice regenerated pilot GAC filter effluents, Phase 2-2.

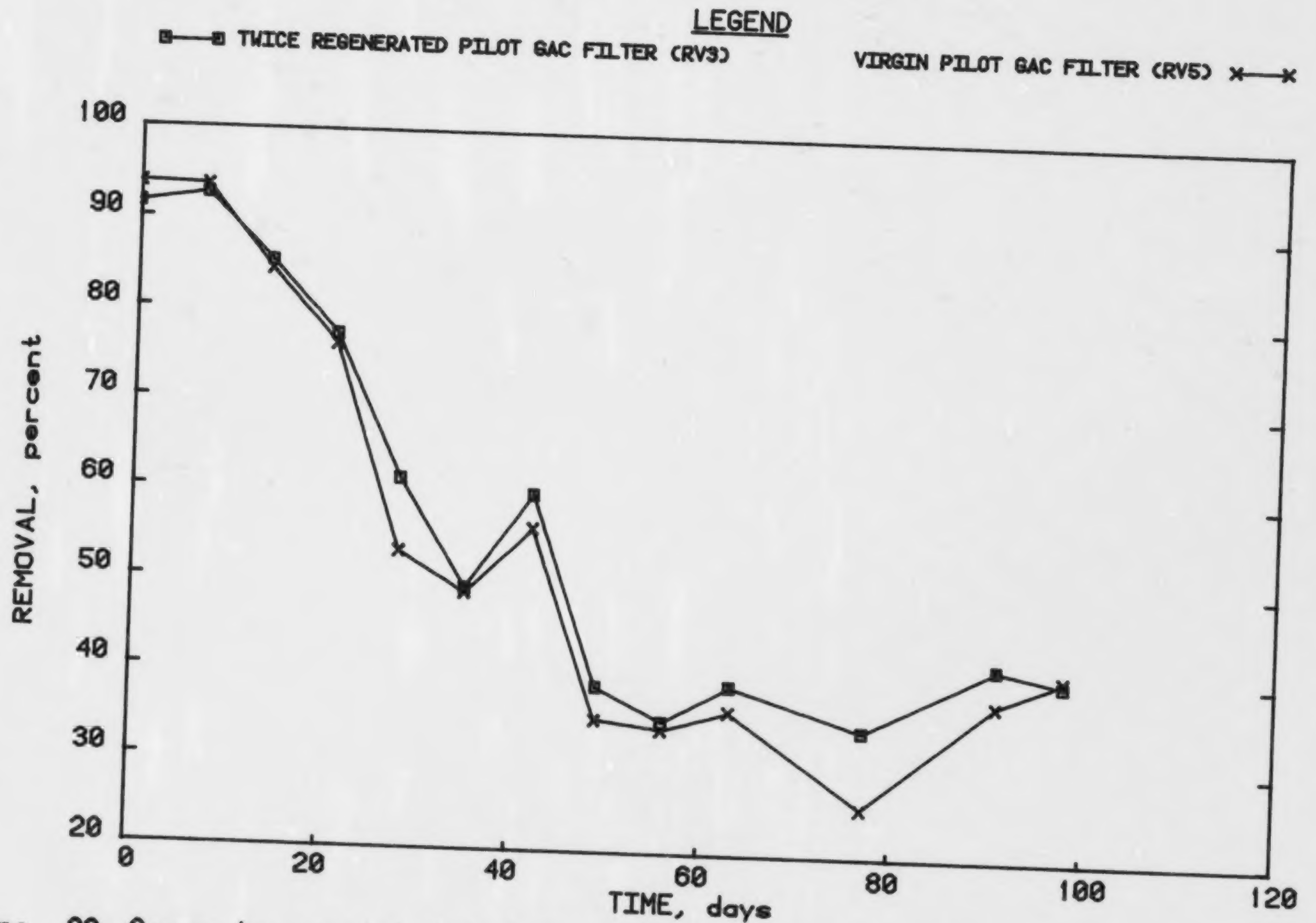


Figure 29. Seven-day simulated distribution syst. THM (STT7) percent removal curves for virgin and twice regenerated pilot GAC filter effluents, Phase 2-2.

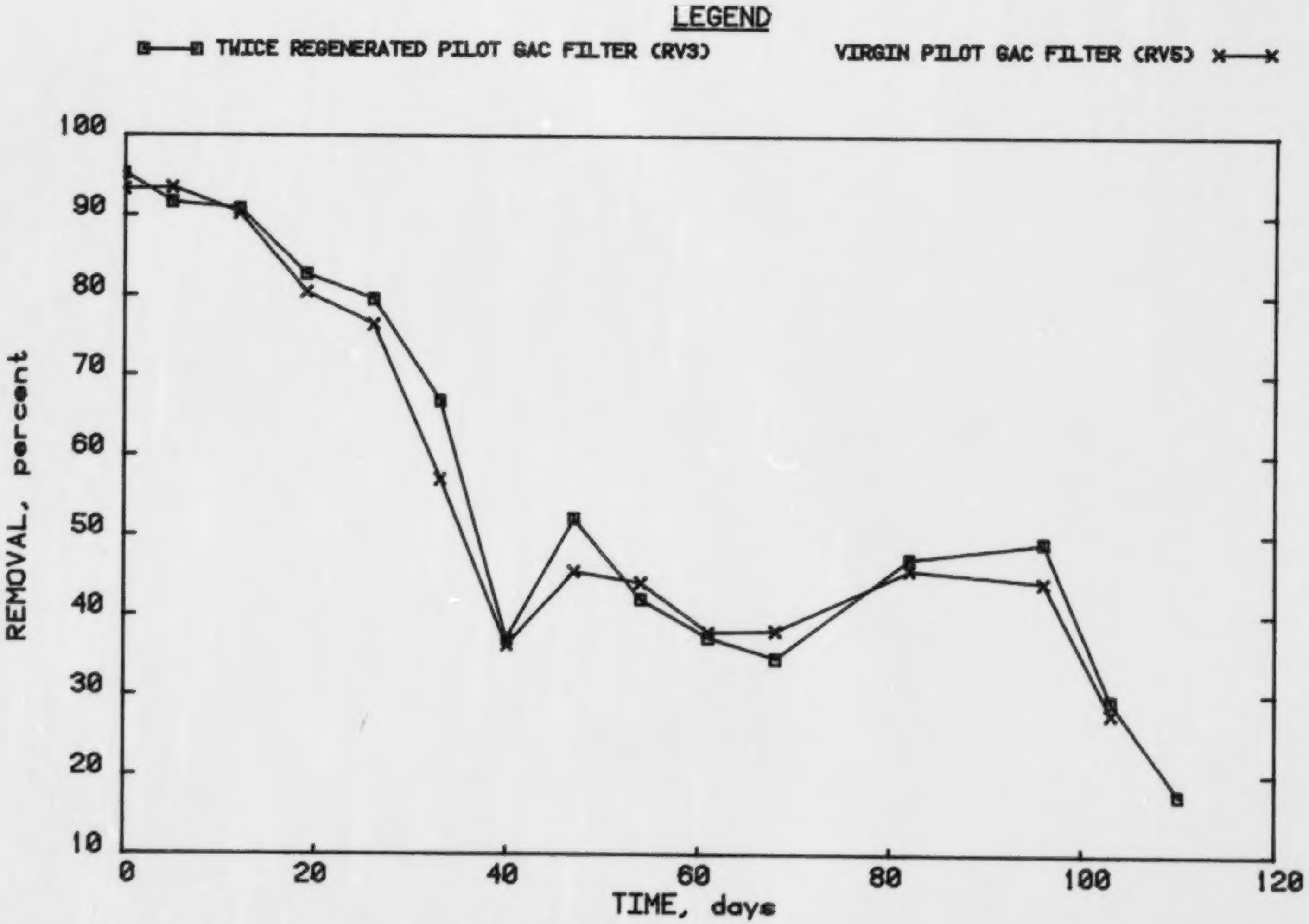


Figure 30. THM formation potential (FTTT) percent removal curves for virgin and twice regenerated pilot GAC filter effluents, Phase 2-2.

water temperatures were lower than during the summer months when shorter bed lives relative to THMs would be expected. Differences in the two systems include the GAC characteristics contained in Table 37 and the GAC costs as indicated in Table 38. Analyses performed included TOC, THMSIMDIST, INSTTHM, THMFP, non-THM purgeable halogenated, purgeable non-halogenated and base/neutral extractable compounds. Due to difficulties in obtaining consistent results from contract laboratories, data concerning the latter two classes of compounds do not provide for any useful evaluation of bituminous/lignite GAC comparative performance. Purgeable halogenated compounds, other than THMs, were seldom seen in sufficient quantities to be useful in comparing these two GACs.

The comparative results of the GACs are contained in Table 39. Only TOC and THMSIMDIST results were compared and only for selected exhaustion criteria. A discussion of the reasons for these selections is contained in Objective 9. Since the preferred criteria identified in Objective 9 (TOC = 1.0 mg/l or STT7 = 0.1 mg/l) did not provide sufficient comparative data, two other related criteria also explained in Objective 9 were included (TOC loading retained ≥ 75% or STT7 loading retained ≥ 75%).

At exhaustion, the preferred GAC will have: 1) lasted a greater number of days, 2) adsorbed a greater weight of contaminants, and 3) cost less per weight of contaminant removed.

As Figures 31 and 32, and Table 39 indicate, bituminous outperformed lignite GAC in almost every case regardless of the exhaustion criterion or parameter. Perhaps this was due to the differences in characteristics such as the greater BET surface area and Iodine number of the bituminous GAC. For example, using the exhaustion criterion of 1.0 mg/l TOC, bituminous GAC lasted 198 days, removed 785 grams of TOC and cost 4.1¢ per TOC gram adsorbed. Lignite GAC lasted only 35 days, removed 248 grams of TOC and cost 6.4¢ per TOC gram adsorbed. These cost figures were merely calculated by dividing the cost of the GAC in the system by the weight of TOC adsorbed. However, since lignite GAC has a lower apparent density and costs less per unit of weight, the cost per gram of contaminant adsorbed needs to be examined more fully.

It was important to consider the adsorbed weight of contaminants from two different perspectives when considering cost: 1) per unit of weight of GAC since GAC is purchased by weight and 2) per unit of volume of GAC since the size and cost of facilities constructed are dependent upon the volume of GAC applied in the treatment process.

The cost estimates in Table 39 are based solely on the cost of GAC and not on facilities or regeneration costs. Given that the bituminous GAC adsorbs more grams of contaminant to exhaustion per unit volume, the use of lignite GAC would require larger tanks to hold proportionately greater volumes of GAC to expect similar removals to that of bituminous GAC. Therefore, although lignite is less expensive per pound, a larger volume of it would have to be applied to match the adsorptive capability of bituminous. Further, given the longer life of the bituminous GAC to exhaustion, lignite

TABLE 37. BITUMINOUS AND LIGNITE GAC CHARACTERISTICS

	Bituminous	Lignite
Weight of GAC, kg (lbs)	16.33 (36.00)	14.40 (31.75)
Apparent Density, gm/ml (lb/cu ft)	0.43-0.46 (27-29)	0.39 (24.3)
Particle Size	12x40	10x30
Surface Area, BET, m^2/g	1100	650
Iodine No., mg/g	1050	600

TABLE 38. BITUMINOUS AND LIGNITE GAC PRICES[a]

	August, 1978	June, 1981
Bituminous	$.65/lb	$.81/lb
Lignite	$.37/lb	$.55/lb

[a] Based on prices quoted in June, 1981 by Westvaco Corp. for bituminous GAC[24] and by ICI Americas, Inc. for lignite GAC.[25]

TABLE 39. COMPARISON OF BITUMINOUS (BIT) AND LIGNITE (LIG) PILOT CONTACTORS FOR SELECTED EXHAUSTION (EXH) CRITERIA

	TOC 1.0 mg/l		STT7 0.1 mg/l		TOC Loading Retained ≥ 75%		STT7 Loading Retained ≥ 75%	
	BIT	LIG	BIT	LIG	BIT	LIG	BIT	LIG
Run Length, Days	198	35	b	b	77	31	175	91
Effluent Conc., mg/l	1.2	1.2	b	b	0.8	1.2	0.05	0.02
Removal, %	31	53	b	b	57	53	34	59
Loading, g	785	248	b	b	492	228	40	30
Load. Retained, %	60	73	b	b	75	75	75	75
Load./GAC wt., g/kg	43	17	b	b	27	16	2	2
GAC Cost/g Load., ¢[a]	4.1	6.4	b	b	6.6	7.7	64	39
TOC Conc. @ STT7 EXH[c]	-	-	b	b	-	-	0.8	1.2
STT7 conc. @ TOC EXH[d]	0.08	0.04	b	b	0.02	0.04	-	-

[a] Based on prices quoted June, 1981.[24,25]

[b] Exhaustion did not occur during this run of 227 days.

[c] The concentration of the TOC when the exhaustion criterion based on STT7 was reached.

[d] The concentration of STT7 when the exhaustion criterion based on TOC was reached.

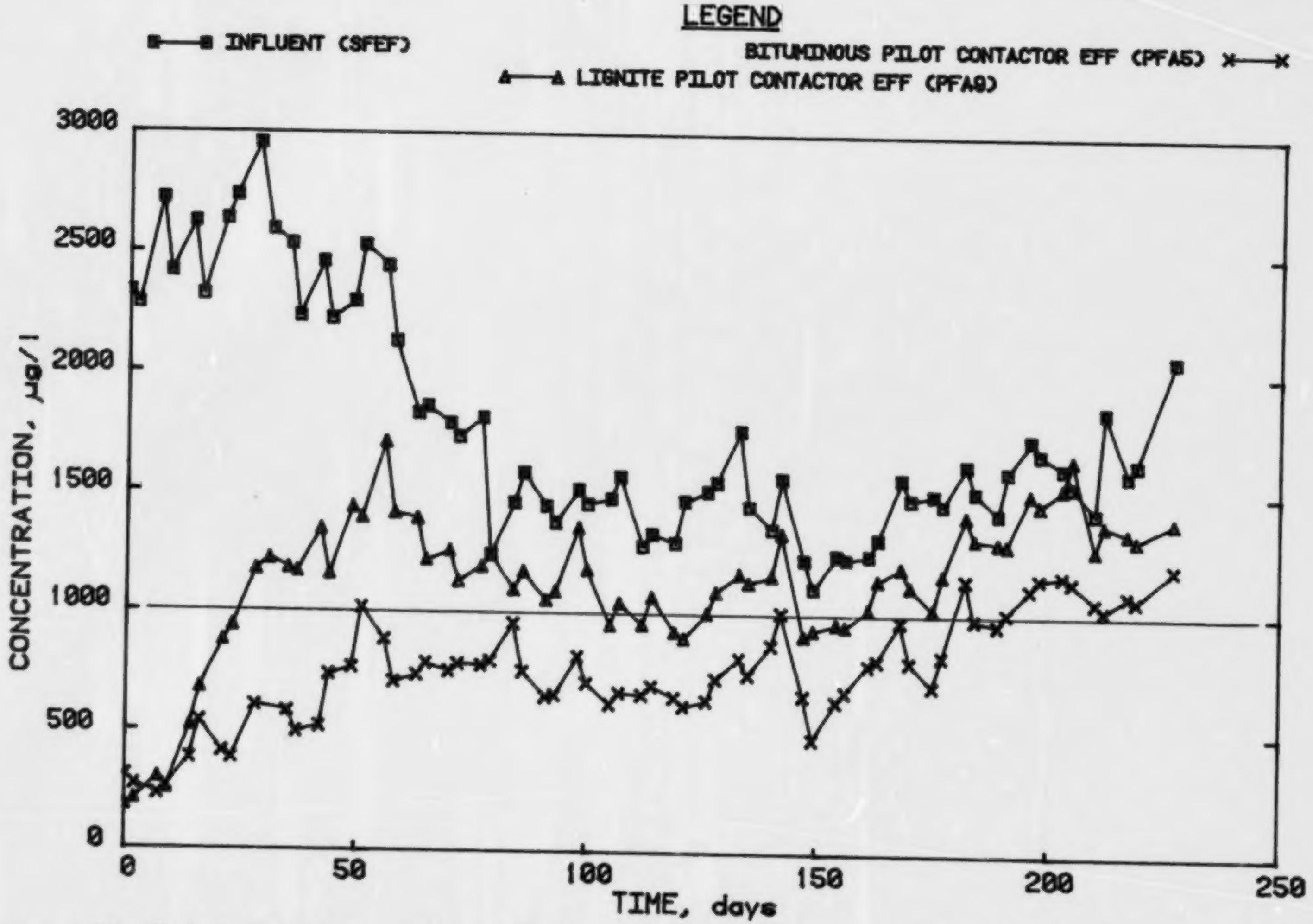


Figure 31. Total organic carbon (TOC) breakthrough curves for bituminous and lignite pilot contactor effluents, Phase 2-0.

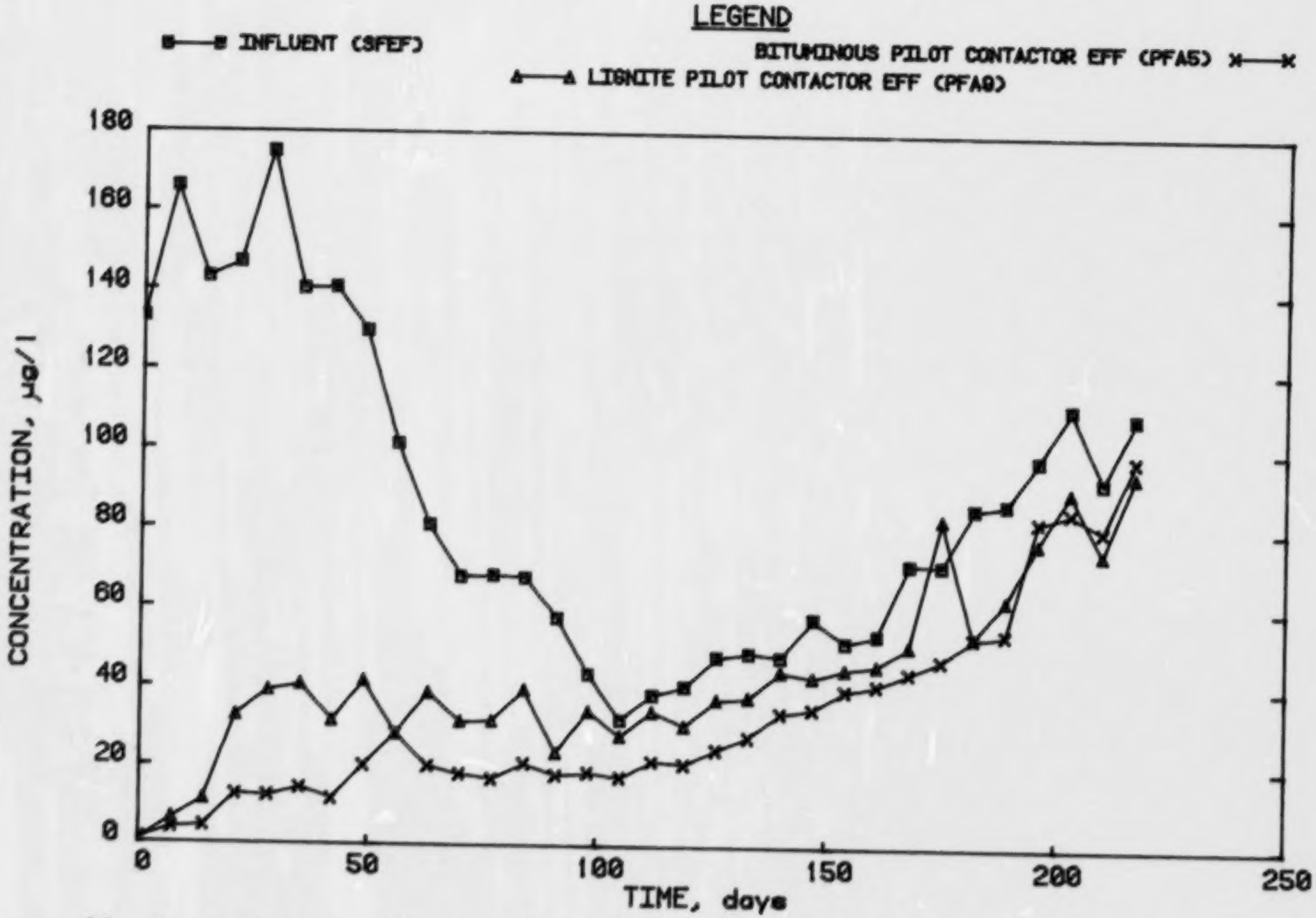


Figure 32. Seven-day simulated distribution system THM (STT7) breakthrough curves for bituminous and lignite pilot contactor effluents, Phase 2-0.

GAC would have to be regenerated five times more often (applying the exhaustion criteria of 1.0 mg/l TOC) at considerable cost.

Due to the fact that the bed lives to exhaustion of the two carbons varied, depending on exhaustion criteria used, and that grant objectives did not include developing costs on the regeneration of lignite GAC, it would be impossible to determine comparative annual costs of the two GACs. However, it seems apparent, based on the available data, that bituminous GAC would be the more cost effective GAC to use in water systems.

Objective 5. To Predict Phase 3 Full-Scale Performance Using Pilot Columns

Phase 2 pilot column data were used to predict the operation and the adsorptive performance of the Phase 3 full-scale GAC systems. This information was also used to predict the life expectancy and, therefore, was useful in estimating the regeneration frequency. The data from this phase not only added to our knowledge gained from Phase 1, but also filled the data voids from Phase 1.

Pilot GAC filters for Phase 2 included two runs which represented both winter, Phase 2-1, and summer, Phase 2-2, conditions. Thus, the performance of GAC under different influent concentrations and temperatures were observed.

The breakthrough curves for TOC, INSTTHM, THMSIMDIST and THMFP from the Phase 2 pilot GAC filter can be found in Figures 33 through 40. From the figures, it is quite apparent that varying influent concentrations resulted in varying breakthrough curves, but the same basic trends existed for both runs. Initially, the GAC removed most of the influent TOC, THMSIMDIST and THMFP concentrations. As the run progressed, the GAC removed a decreasing amount of the influent concentration until a steady state was reached for the remainder of the run. At steady state, the GAC removed a constant percentage of the influent concentration. The trend observed in the breakthrough curves for INSTTHM were similar to those detailed above except that instead of reaching a steady state, the effluent concentration eventually equalled the influent and then ultimately exceeded it. For the most part, the Phase 3 GAC filters tended to mimic these results. In order to estimate or predict the regeneration frequency for the Phase 3 GAC filters, TOC and THMSIMDIST exhaustion criteria were established.

The TOC exhaustion criterion was defined as the point at which the three-week running average for TOC exceeded 1,000 μg/l (as represented by the intersection of the treatment goal line and the breakthrough curve when the average of any three-week set exceeds the goal). The pilot GAC filters would have required regeneration after 24 days of operation for Phase 2-1 and 34 days for Phase 2-2. This meant that the full-scale system in Phase 3 would likely require regeneration approximately every 29 days. Applying this TOC exhaustion criterion to the Phase 3 GAC filters resulted in an average operating life of 24 days which approximated the predicted 29 days.

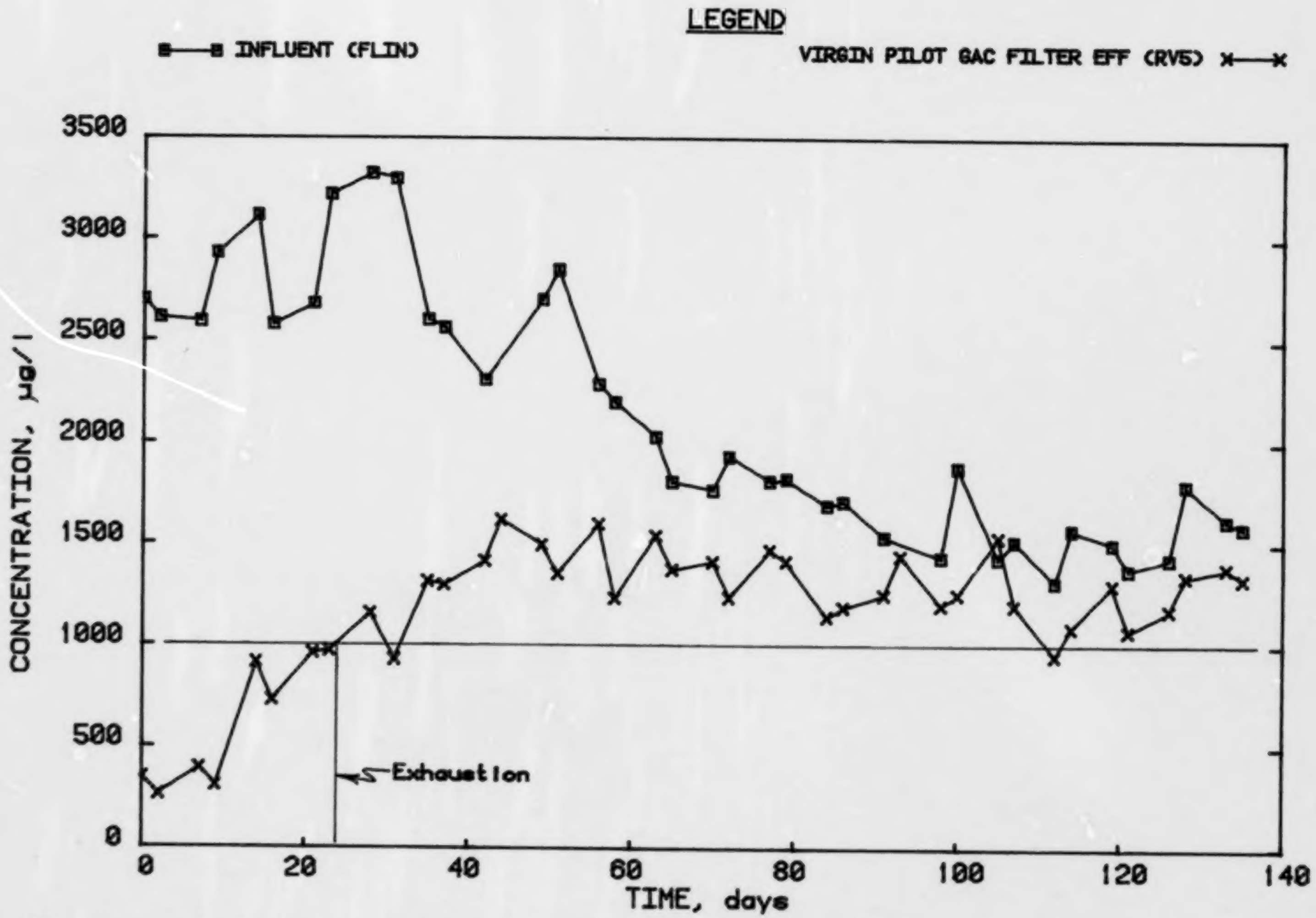


Figure 33. Total organic carbon (TOC) breakthrough curve for virgin pilot GAC filter, Phase 2-1.

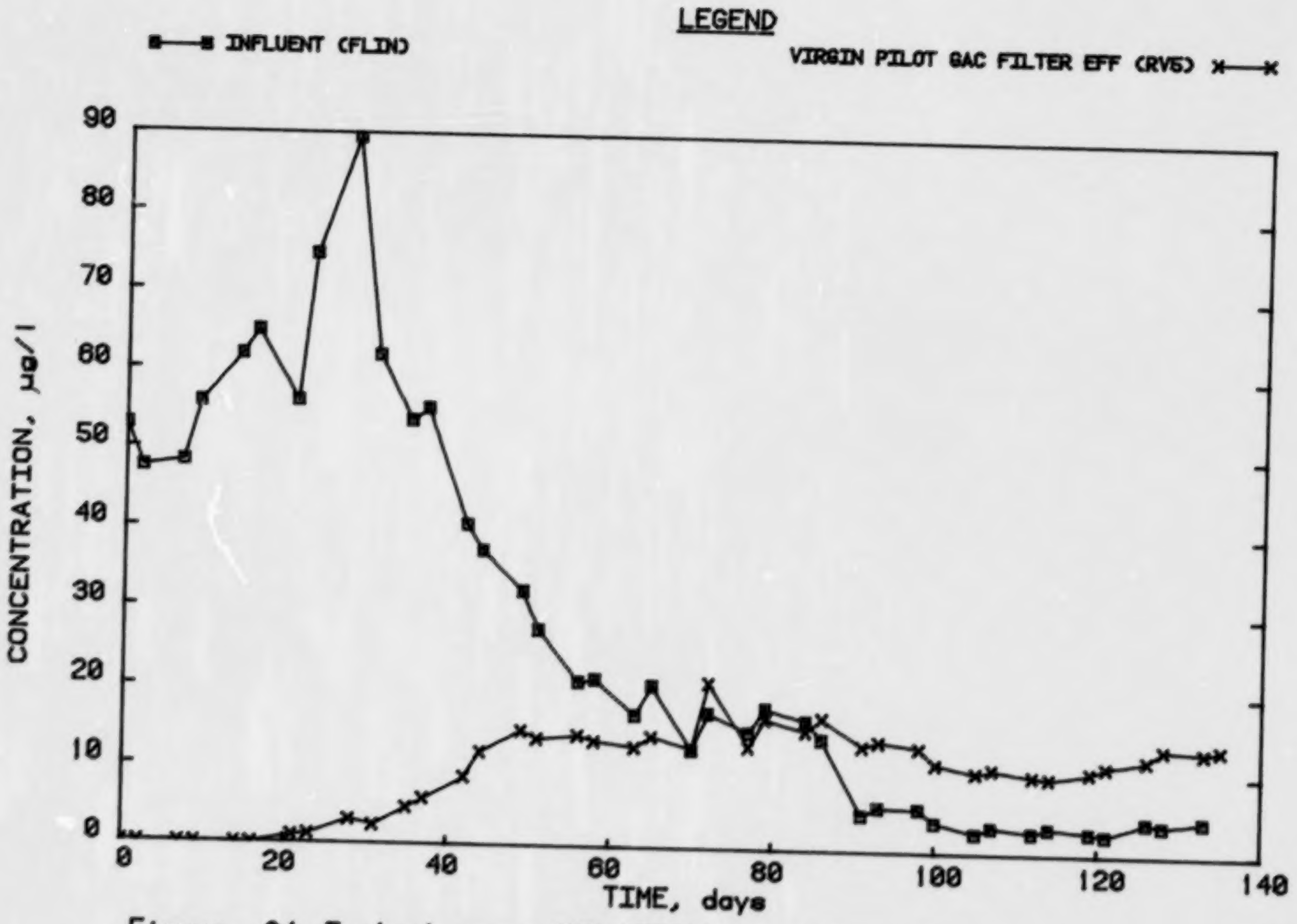


Figure 34. Instantaneous THM (ITTT) breakthrough curve for virgin pilot GAC filter, Phase 2-1.

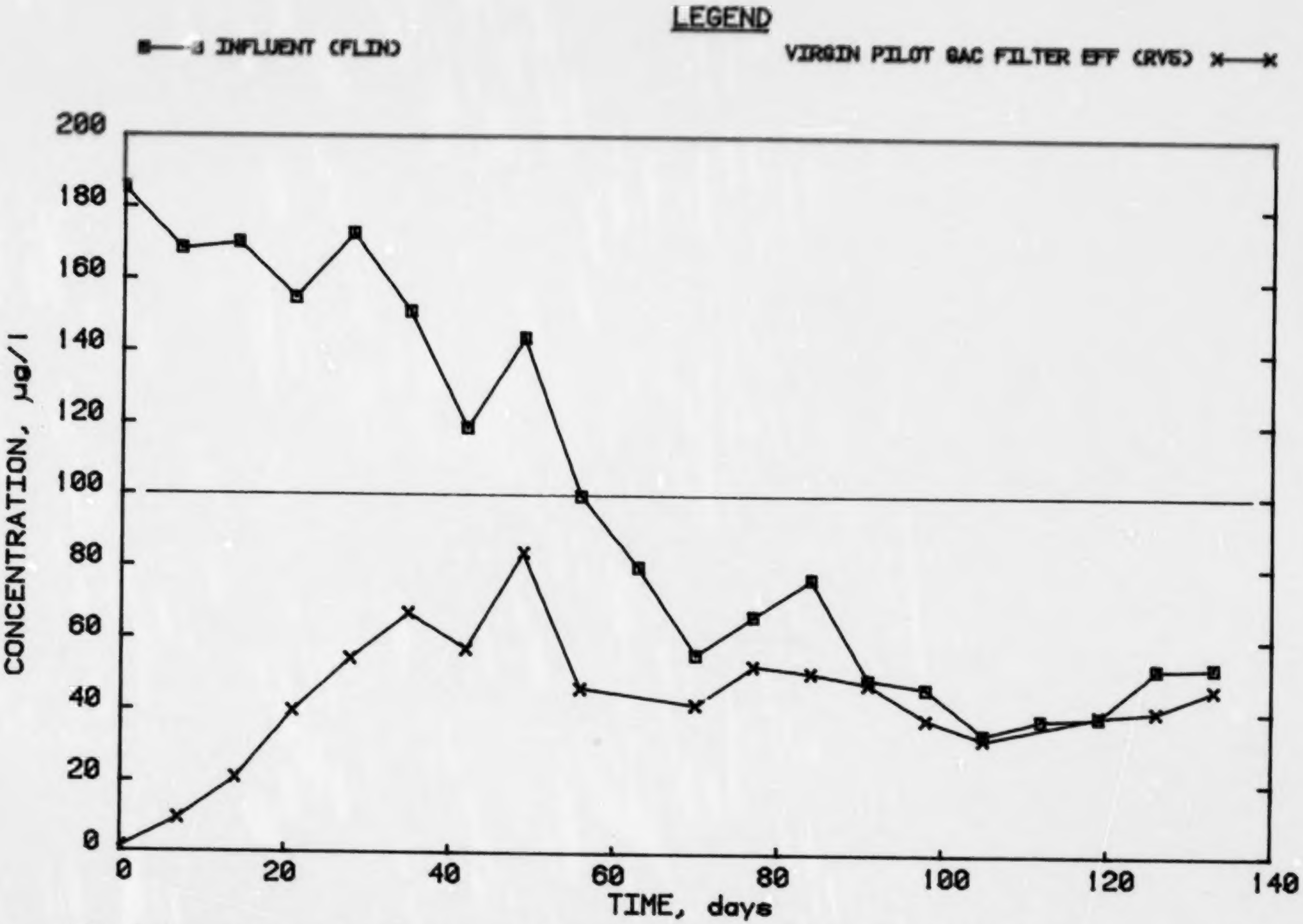


Figure 35. Seven-day simulated distribution system THM (STT7) breakthrough curve for virgin pilot GAC filter, Phase 2-1.

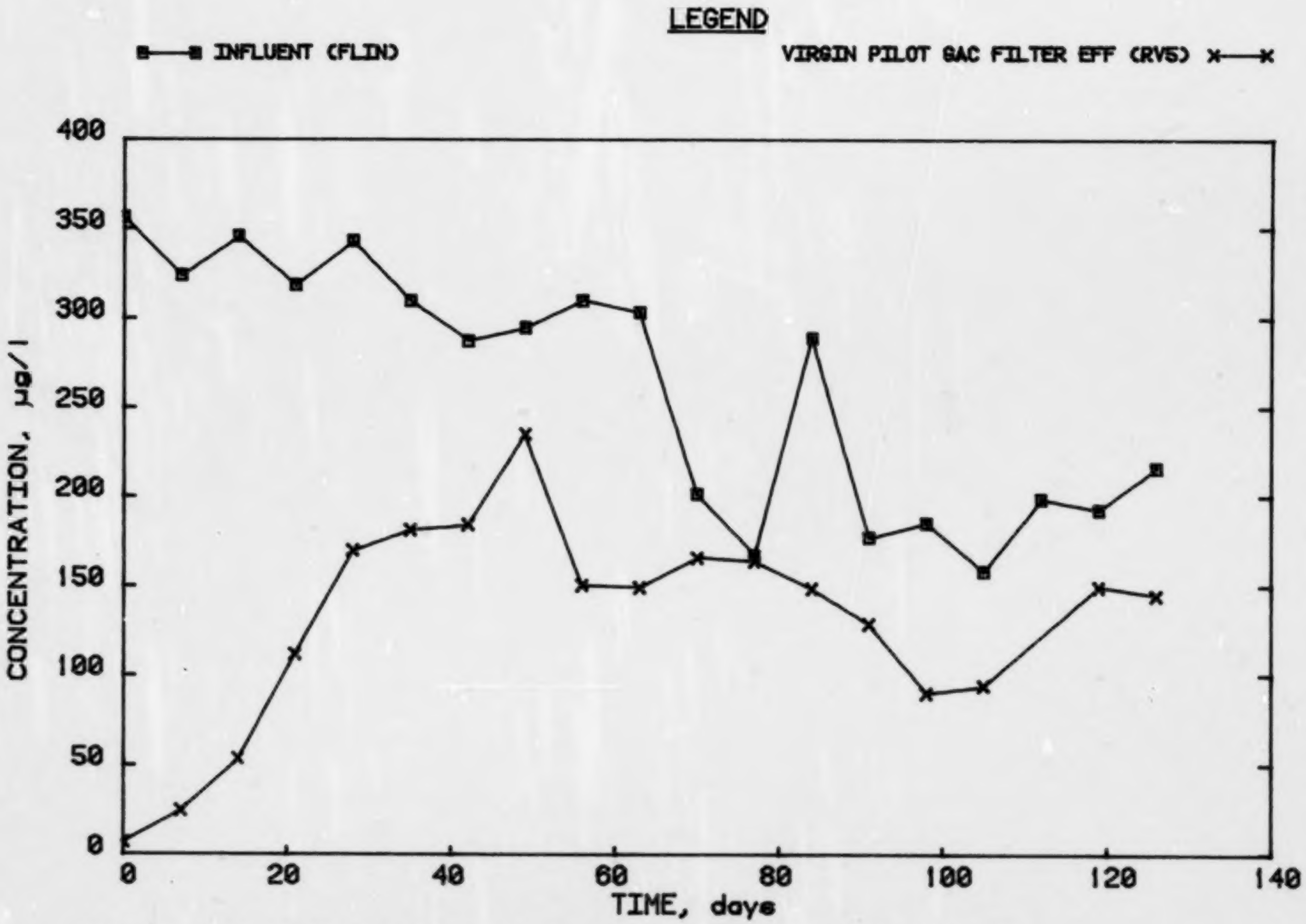


Figure 36. THM formation potential (FTTT) breakthrough curve for virgin pilot GAC filter, Phase 2-1.

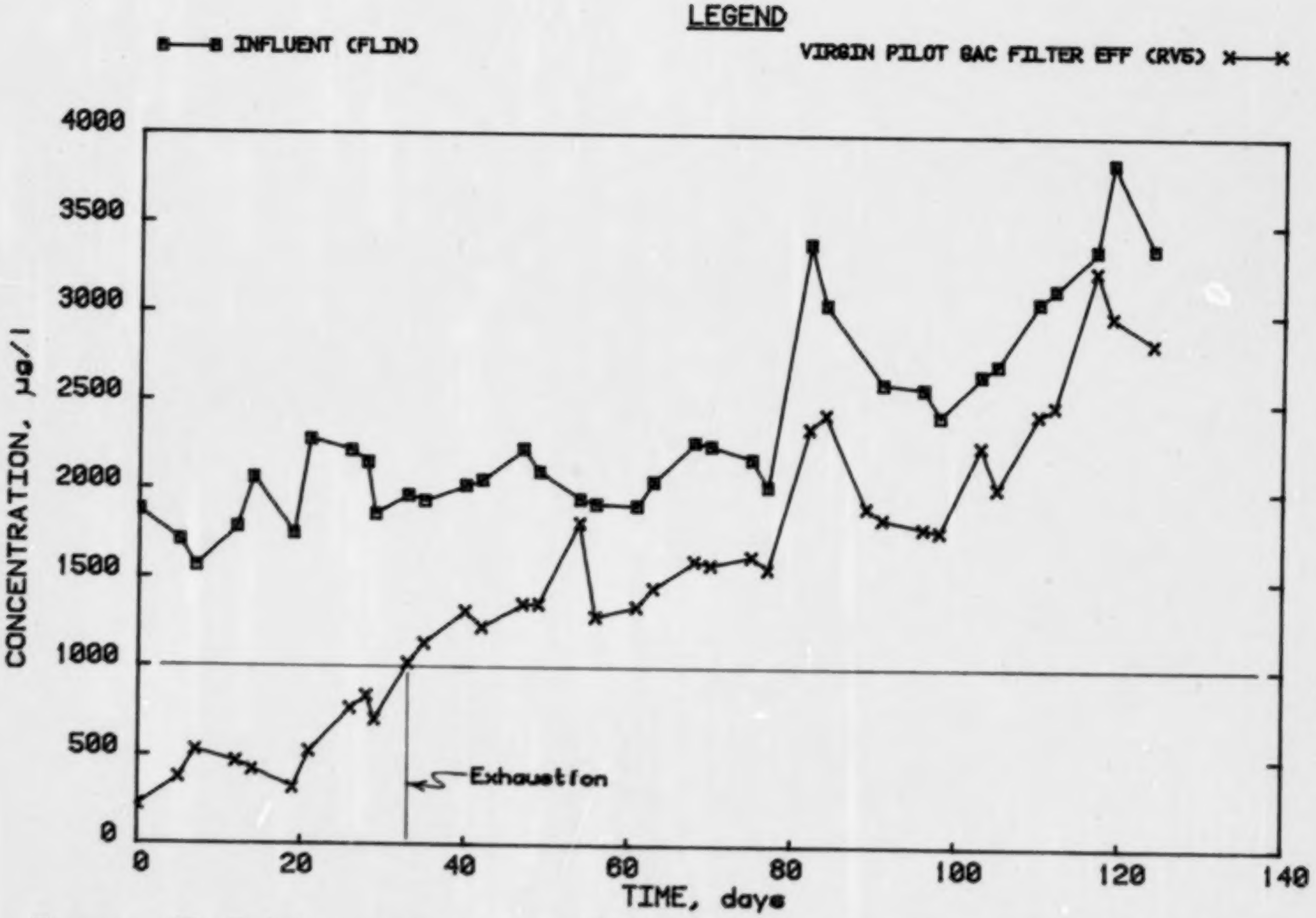


Figure 37. Total organic carbon (TOC) breakthrough curve for virgin pilot GAC filter, Phase 2-2.

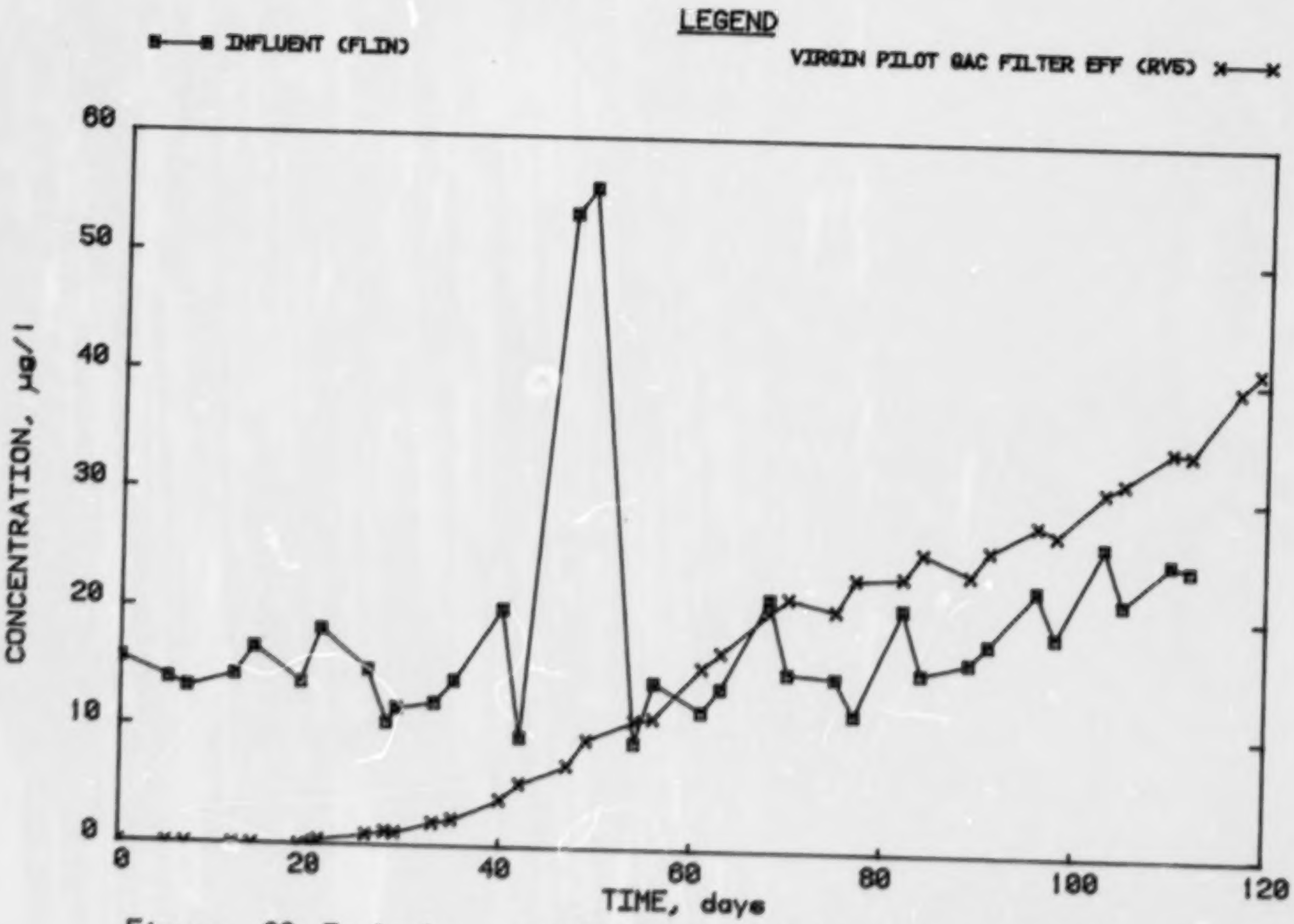


Figure 38. Instantaneous THM (ITTT) breakthrough curve for virgin pilot GAC filter, Phase 2-2.

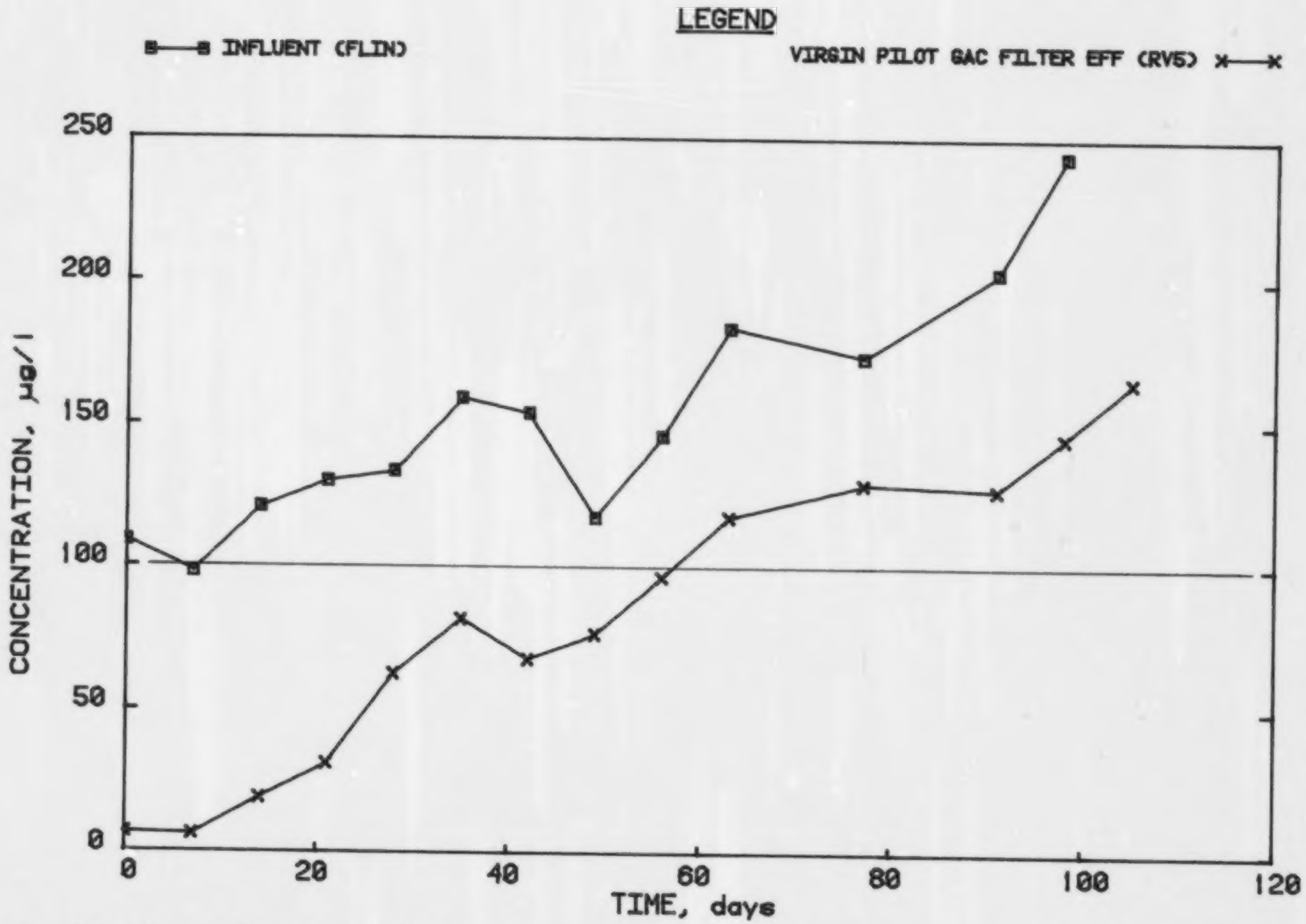


Figure 39. Seven-day simulated distribution system THM (STT7) breakthrough curve for virgin pilot GAC filter, Phase 2-2.

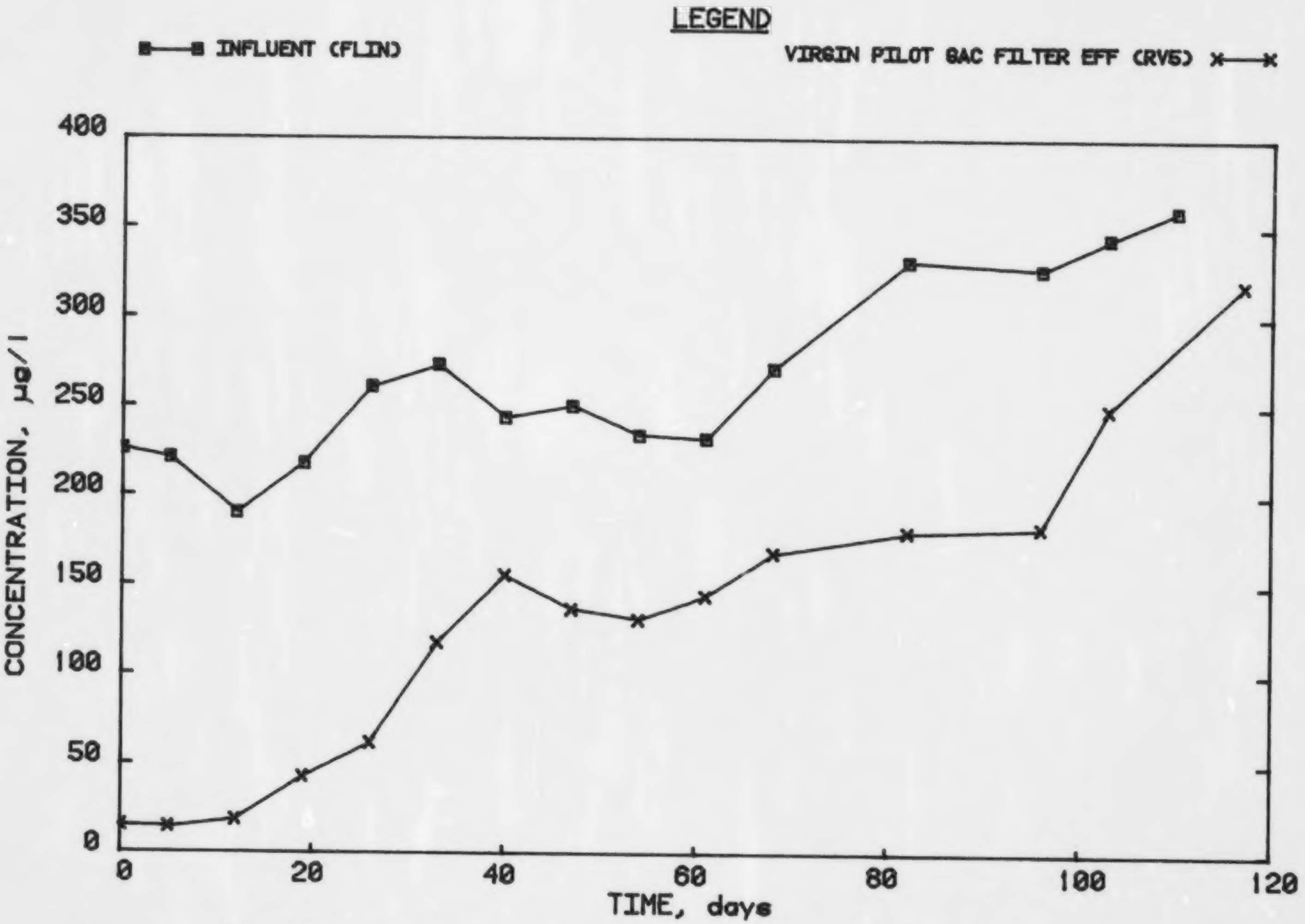


Figure 40. THM formation potential (FTTT) breakthrough curve for virgin pilot GAC filter, Phase 2-2.

The THMSIMDIST treatment goal was not useful to this objective since different storage times (seven days in Phase 1 and three days in Phase 3) were used in the analytical process. Figures 35 and 39 are presented to point out one problem with using THMSIMDIST as an exhaustion criterion. The criterion was only valid during the summer months (Figure 39) because during the winter months (Figure 35) the rate of THMSIMDIST formation was limited by the cooler water temperatures and by lower concentrations of precursors.

The pilot contactor for Phase 2 involved only one run which occurred under winter, or cold water temperature, conditions. The only operational problem encountered during this run involved maintaining proper flow through the columns. As mentioned earlier, this system consisted of four 10.2 cm (4 in) I.D. glass columns in series containing 0.9, 1.2, 1.2 and 1.2 m (3, 4, 4 and 4 ft) of GAC, respectively, and a hydraulic loading of 302 lpm/sq m (7.0 gpm/sq ft). On rundays 91 and 141, it was necessary to backwash all four pilot columns in order to maintain the 302 lpm/sq m (7.0 gpm/sq ft) loading rate. A backwash criterion was established for the full-scale contactors which stated that if the drop across the bed exceeded 138 kPa (20 psig), the contactor would be backwashed. However, this criterion was never met during Phase 3 and, therefore, it was not necessary to backwash any contactors.

The breakthrough curves for TOC, INSTTHM, THMSIMDIST and THMFP from the pilot contactor can be found in Figures 41 through 44. The same trend of breakthrough, gradual rise and steady state for TOC, THMSIMDIST and THMFP, described earlier for pilot GAC filters, was observed here. Also, as before, the INSTTHM in the effluent eventually equalled and then exceeded the influent INSTTHM concentration.

The TOC exhaustion criterion, defined earlier, resulted in the prediction of 180 days of operation for contactors before requiring regeneration. Applying this exhaustion criterion to the Phase 3 contactors, resulted in an average operating life of 89 days with a range of 36 to 168 days. It can be seen that the predicted life of 180 days was at the upper range of the observed values. This emphasizes the fact that caution should be employed when using only one run upon which to base projections.

From Figure 43, it can be seen that the THMSIMDIST concentration in the influent and effluent was increasing. This increase in THMSIMDIST concentration was due to the increasing water temperature and increasing concentrations of precursors. However, the effluent THMSIMDIST concentration never exceeded the 100 µg/l exhaustion criterion.

For the most part, the pilot systems did give a good indication of what to expect from full-scale systems. However, the main objective of this grant was the operation of full-scale systems and not pilot systems. Anyone wishing to use pilot systems to predict full-scale systems should perform several runs covering all seasons of the year.

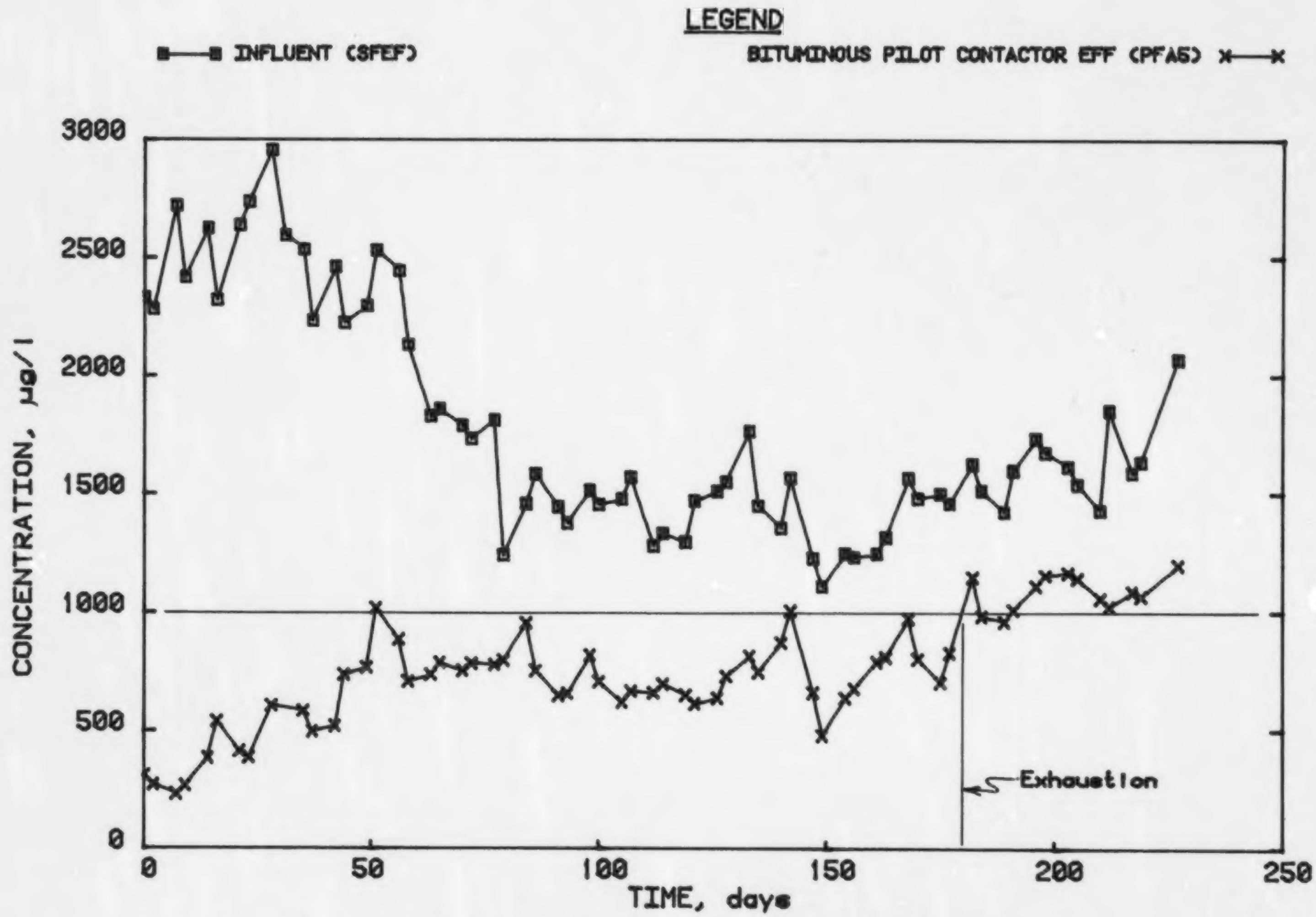


Figure 41. Total organic carbon (TOC) breakthrough curve for bituminous pilot contactor, Phase 2-0.

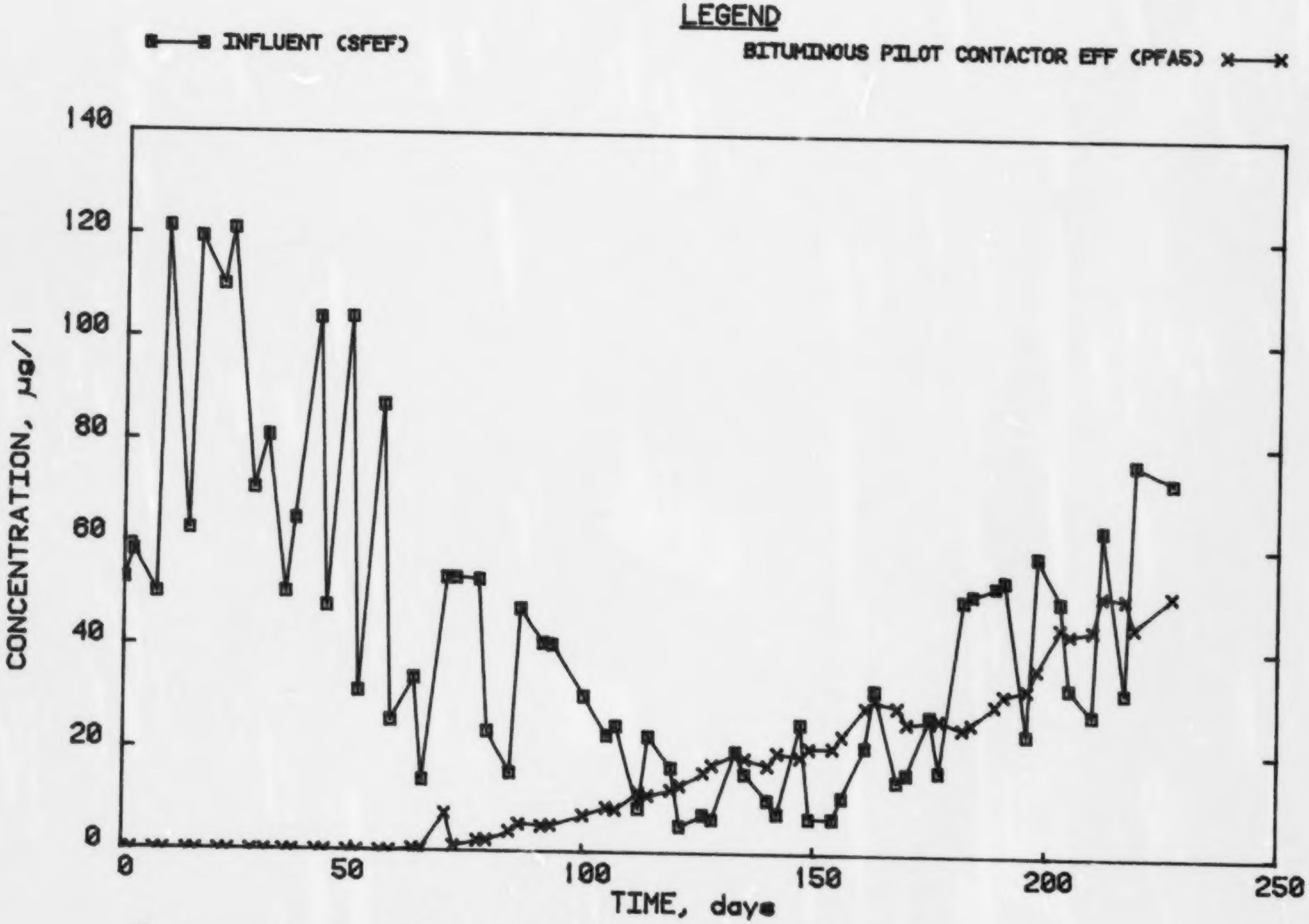


Figure 42. Instantaneous THM (ITTT) breakthrough curve for bituminous pilot contactor, Phase 2-0.

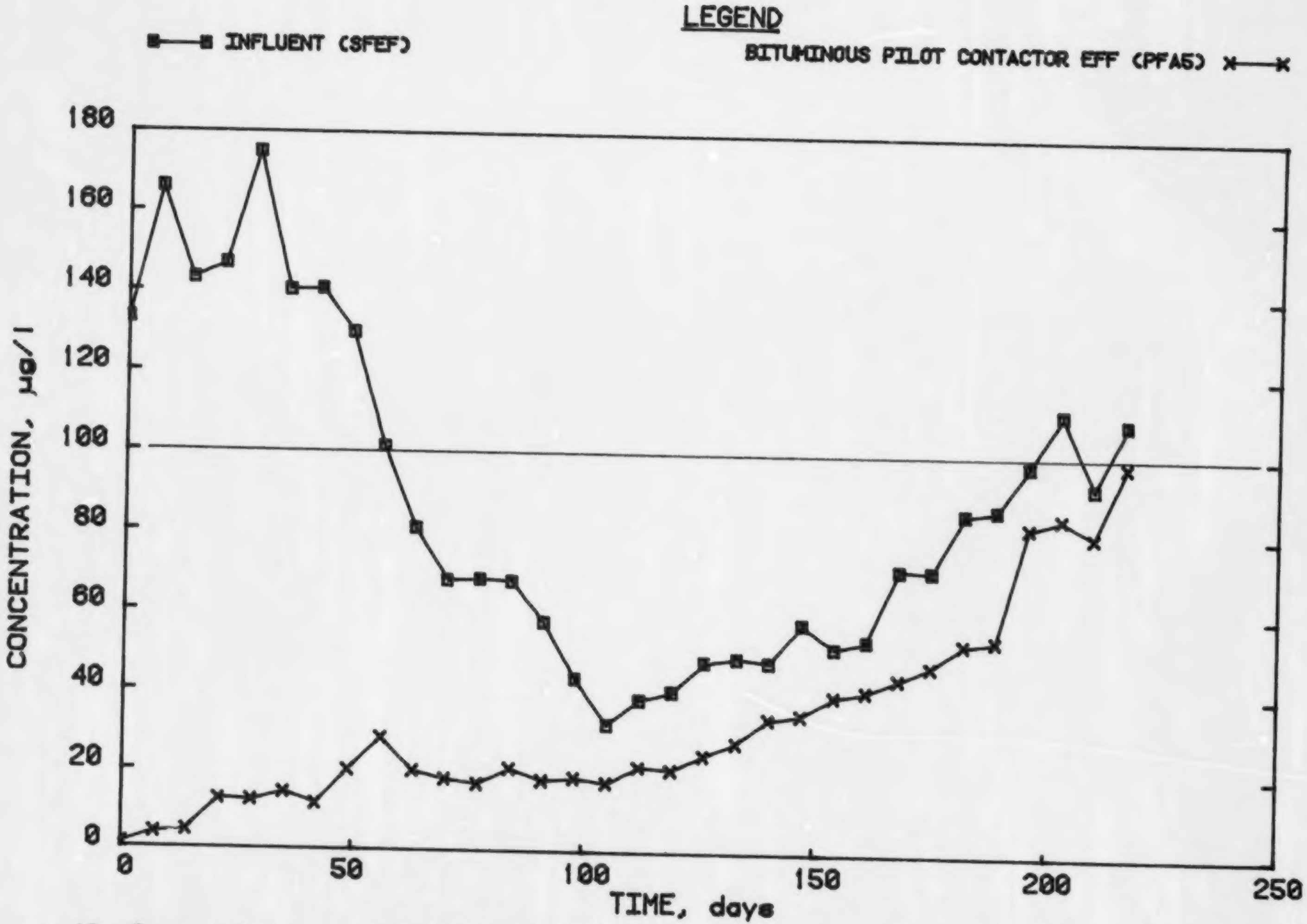


Figure 43. Seven-day simulated distribution system THM (STT7) breakthrough curve for bituminous pilot contactor, Phase 2-0.

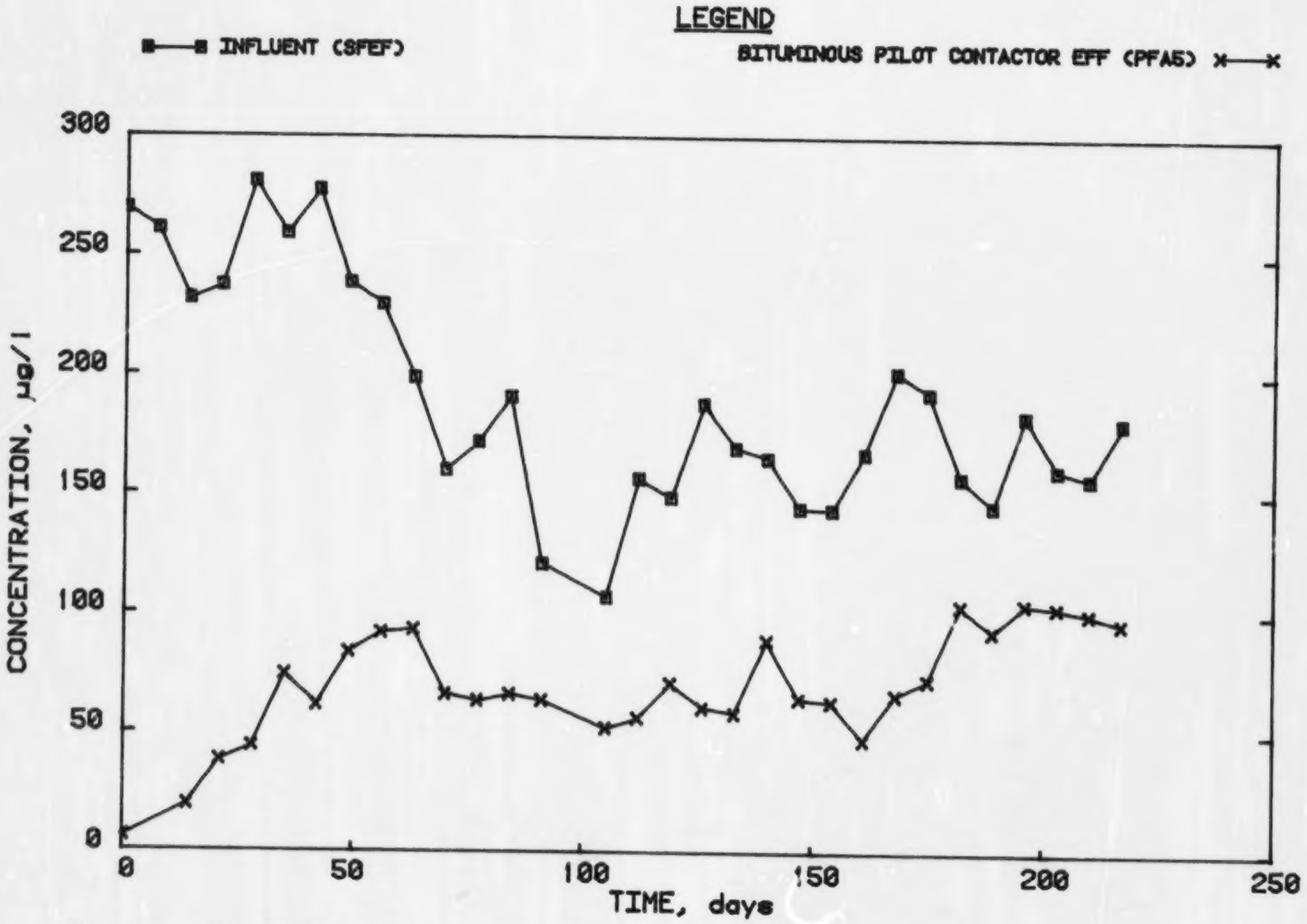


Figure 44. THM formation potential (FTTT) breakthrough curve for bituminous pilot contactor, Phase 2-0.

PHASE 3. FULL-SCALE GAC FILTERS AND CONTACTORS WITH ON-SITE REGENERATION

Objective 6. To Compare the Relative Performance of Full-Scale GAC Filters and Contactors

As mentioned earlier, Phase 3 dealt with the study of GAC systems in two operational modes. In the first mode, the systems were acting as GAC filters or sand replacement systems. Therefore, the GAC acted both as a filter for carryover solids and as an adsorbent material for dissolved organics. In the second mode, the systems were used as adsorbers only since they received water which already had the carryover solids removed by conventional sand filters.

Comparison of Equal Contact Times--

In this section, the effluent from GAC filters was compared to the effluent of a sample point in the contactor with a similar EBCT. This comparison helped to show what effect, if any, the filtering function of a GAC filter had on its ability to adsorb dissolved organics. The EBCT for a filter is 7.5 minutes which is within 5% of the 7.2 minutes EBCT for the contactor sample point used.

Two comparison runs were performed during Phase 3. The first run matched 15AE and D7 from Phase 3-0, while the second run matched 15AE and C7 from Phase 3-1. For the most part, the findings from 15AE and D7, Phase 3-0, were similar to those from 15AE and C7, Phase 3-1. Since these two systems paralleled, the discussion will be limited to 15AE and D7, Phase 3-0, unless otherwise stated. The matching graphs for 15AE and C7, Phase 3-1, in addition to other graphs for both comparisons can be found in Volume Two.

Figures 45 through 49 are the breakthrough curves for TOC, THMSIMDIST, INSTTHM and THMFP. These plots serve two purposes: 1) they enable the comparison of similar EBCT in two different operational modes (GAC filters and contactors); and 2) they present a comparison of what the consumer would receive with and without GAC treatment.

Figure 45 shows that the GAC filter effluent TOC concentration was slightly higher than the similar EBCT contactor concentration. However, the GAC filter TOC influent concentration was also slightly higher. Overall, it appears that the two systems were performing in a similar manner.

Figure 46 shows that the THMSIMDIST curves for the two similar EBCTs are identical. The two influent THMSIMDIST concentration curves are also identical. It appears that the solids removed by the sand filters interfered little with the GAC's ability to remove THMSIMDIST precursor.

Figure 47 shows that the GAC filter influent INSTTHM concentration is slightly lower than the influent concentration for the contactor. This can be explained by the fact that the influent to the contactor was the effluent from the sand filter which provided a longer reaction time between the THM precursors and chlorine. The average influent concentration throughout the

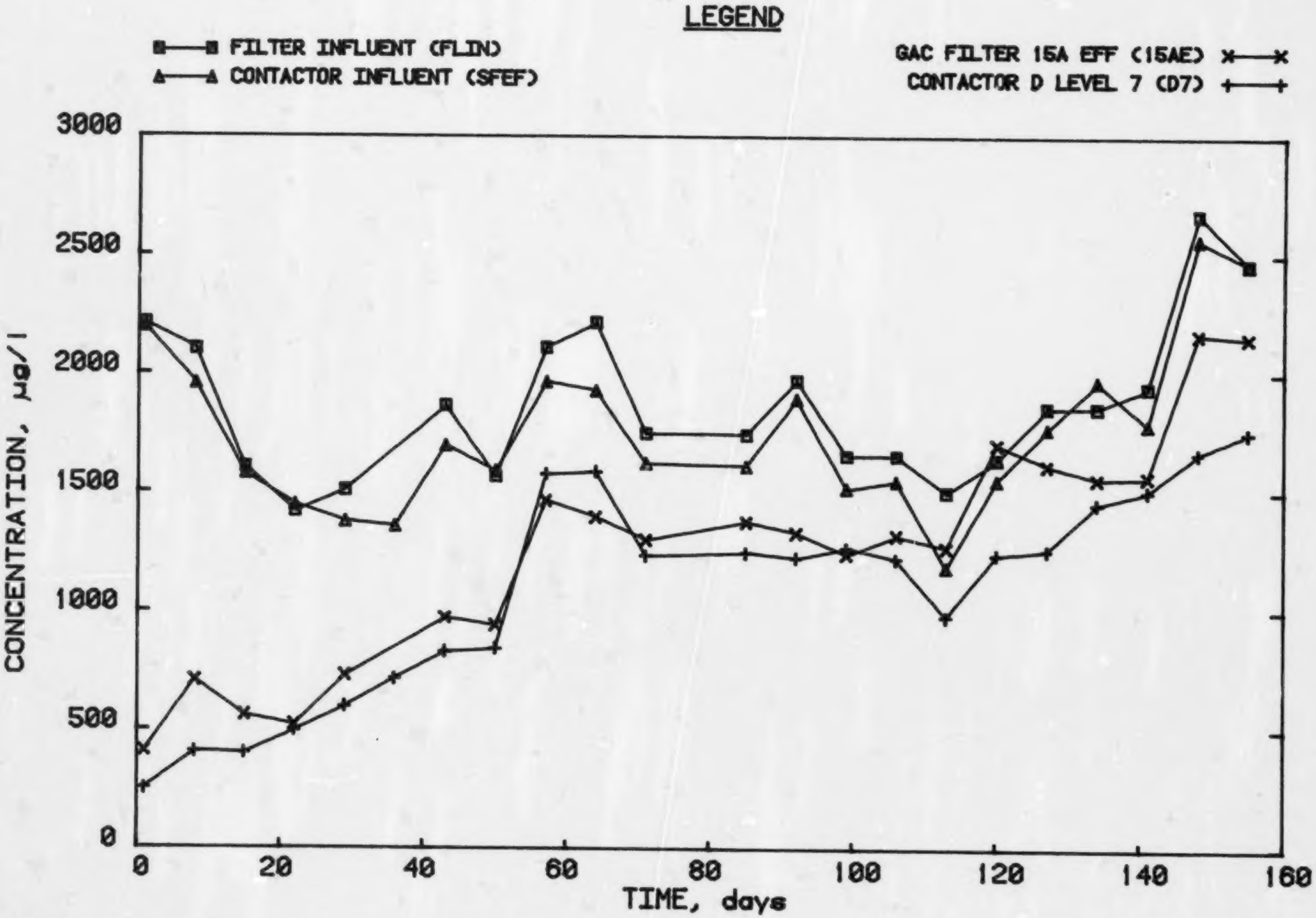


FIGURE 45. Total organic carbon (TOC) breakthrough curves for GAC Filter 15A effluent and Contactor D level 7, Phase 3-0.

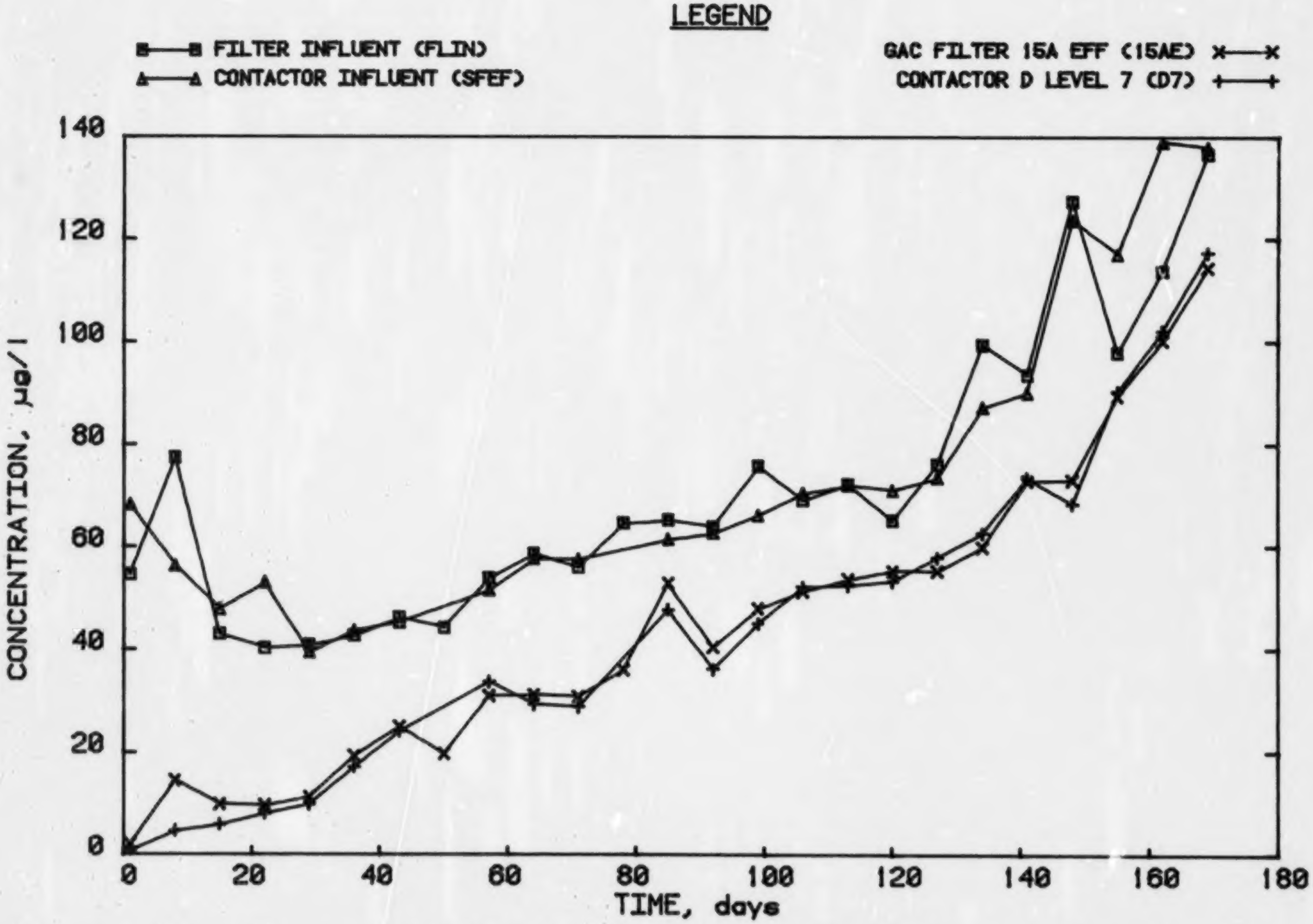


FIGURE 46. Three-day simulated distribution system THM (STT3) breakthrough curves for GAC Filter 15A effluent and Contactor D level 7, Phase 3-0.

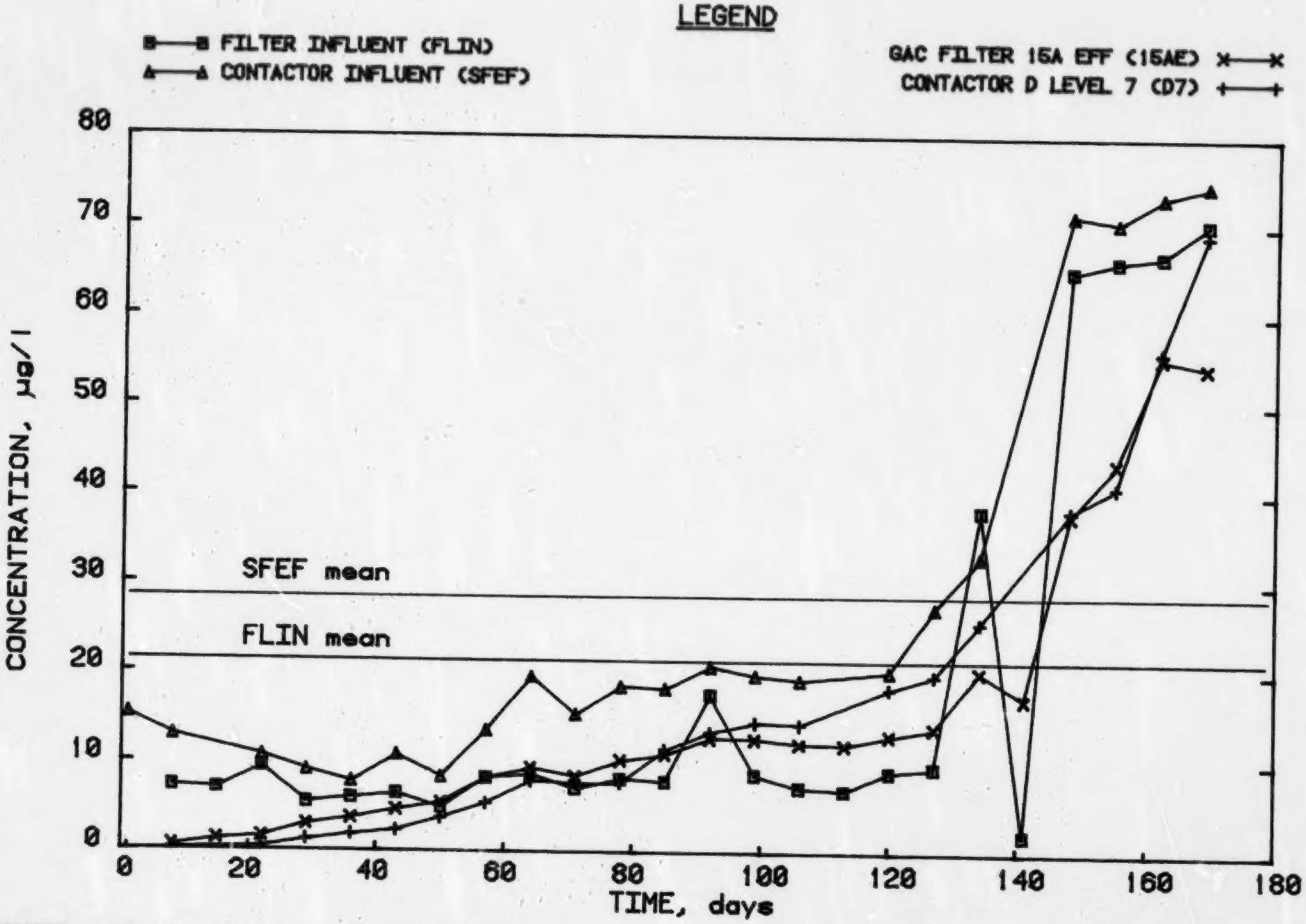


FIGURE 47. Instantaneous THM (ITTT) breakthrough curves for GAC Filter 15A effluent and Contactor D level 7, Phase 3-0.

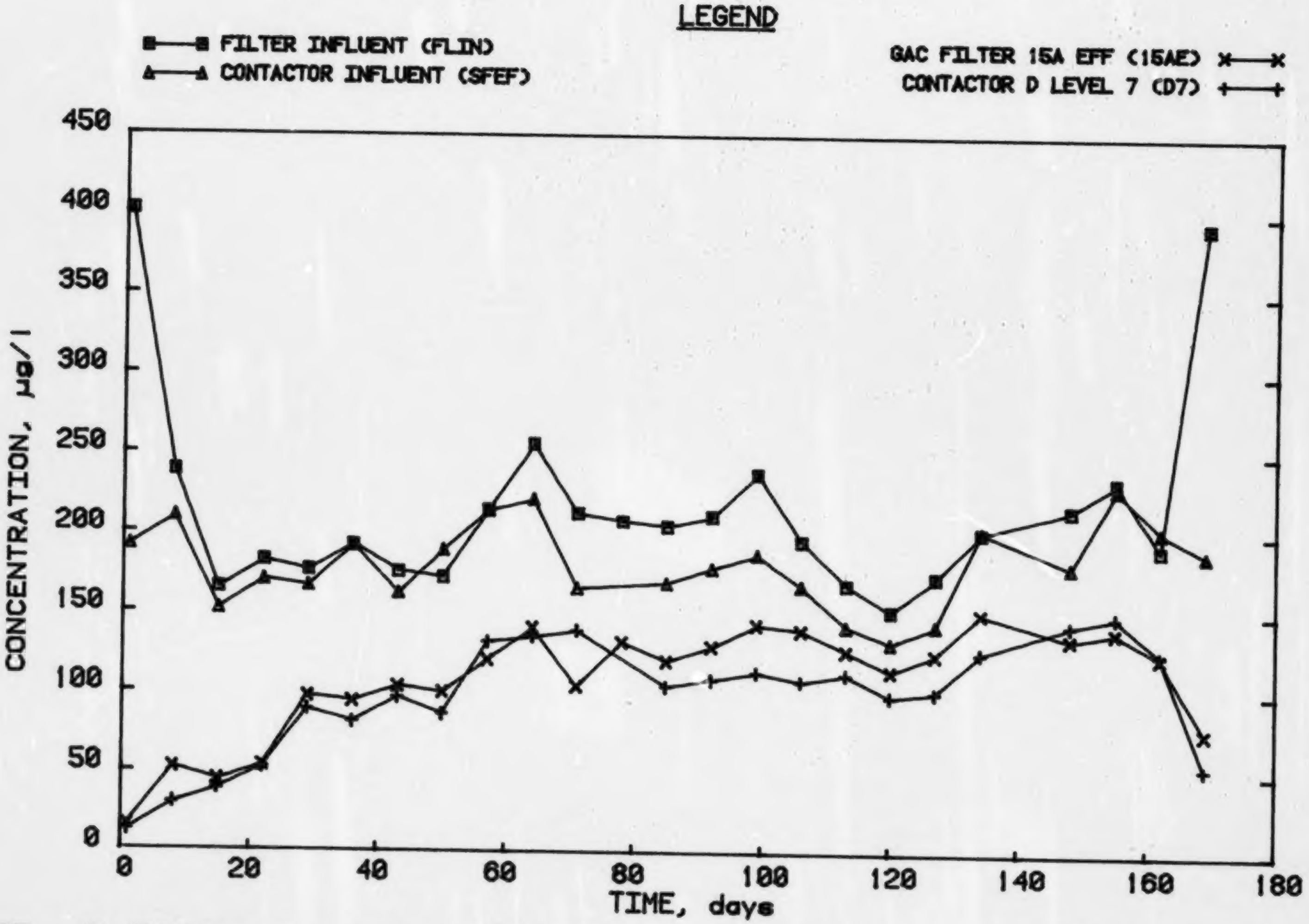


FIGURE 48. THM formation potential (FTTT) breakthrough curves for GAC Filter 15A effluent and Contactor D level 7, Phase 3-0.

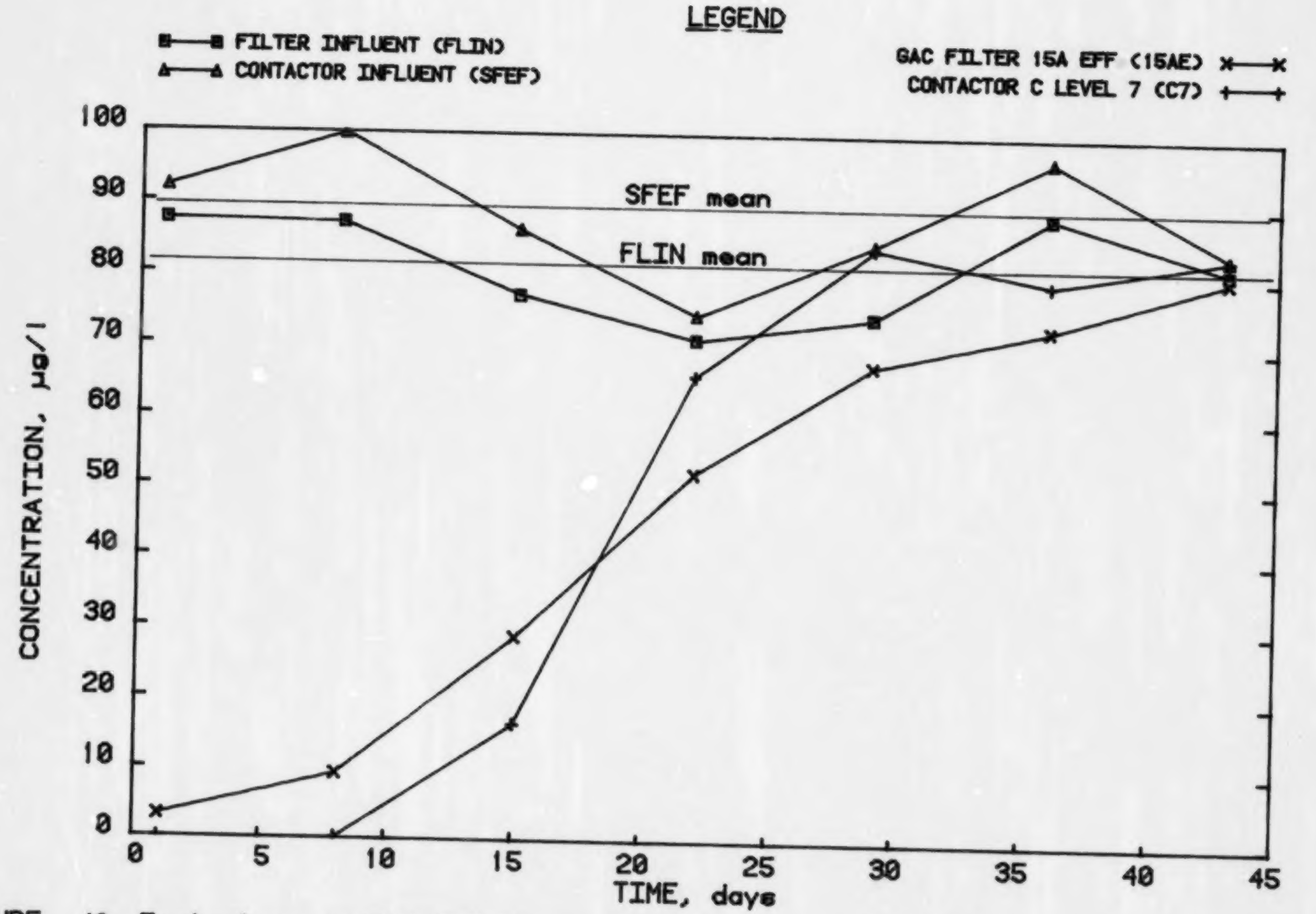


FIGURE 49. Instantaneous THM (ITTT) breakthrough curves for GAC Filter 15A effluent and Contactor C level 7, Phase 3-1.

run to the GAC filter was 21.1 µg/l compared to 28.2 µg/l average influent concentration for the contactor. Although a rigid comparison was not possible, it appears that GAC systems with similar EBCTs followed the same trends. Figure 48 is a plot of the INSTTHM breakthrough curves for 15AE and C7, Phase 3-1. In this case, the two influents were closer in concentration due to the warmer water temperature causing the rate of formation to increase, thus reducing the effect of the longer contact time. The average influent concentration throughout the run to the GAC filter was 81.0 µg/l which was similar to the 89.4 µg/l average influent concentration for the contactor. Figure 49 is a plot of the percent removal of influent INSTTHM for 15AE and C7, Phase 3-0, which shows that the two systems performed roughly the same.

Figure 50 shows that the GAC filter effluent THMFP concentration was slightly higher than the similar EBCT contactor concentration. This difference can be explained by the differences in INSTTHM concentration observed in Figure 47. Figure 51 shows the two systems were very similar in their removal of influent THMFP.

Tables 40 and 41 contain the minimum, maximum and average values for the purgeable halogenateds (other than the INSTTHMs) for 15AE and D7, Phase 3-0, and 15AE and C7, Phase 3-1, respectively. In both tables, the influent concentration, for the most part, approached the lower detection limit of the instrument. The two similar EBCT systems performed approximately the same. If the dichloromethane concentration represents a real value and not a laboratory artifact, the GAC has little adsorptive capacity for it. GAC was very effective in removing low concentrations of other purgeable halogenated compounds.

Tables 42 and 43 contain the minimum, maximum and average values for the purgeable non-halogenated organic compounds for 15AE and D7, Phase 3-0, and 15AE and C7, Phase 3-1, respectively. For the most part, the influent concentrations approached the detector's lower limit. Except for ethylbenzene for 15AE and D7, Phase 3-0, the two similar EBCT systems performed the same. Some of the results contained in Table 42 may be due to laboratory artifacts since the analytical method was still being modified during this run. It appears from Table 43 that at lower µg/l influent concentrations, GAC was ineffective to moderately effective in removing benzene and ethylbenzene. Toluene and hexane were removed more effectively. Tetralin and o-xylene were not detected, except for one case of o-xylene in the influent.

CAOX analyses were performed on samples from 15AE and D7, Phase 3-0. Figure 52 is a plot of CAOX breakthrough curves for 15AE and D7, Phase 3-0. Since the CAOX formation was dependent on chlorine contact time, the previous discussion on differing influent concentrations for INSTTHM also applies here. Generally, the two similar EBCT systems follow each other. On runday 113, it appears that either 15AE was desorbing CAOX or that the datum is questionable. The datum on runday 85 for the contactor influent is also questionable.

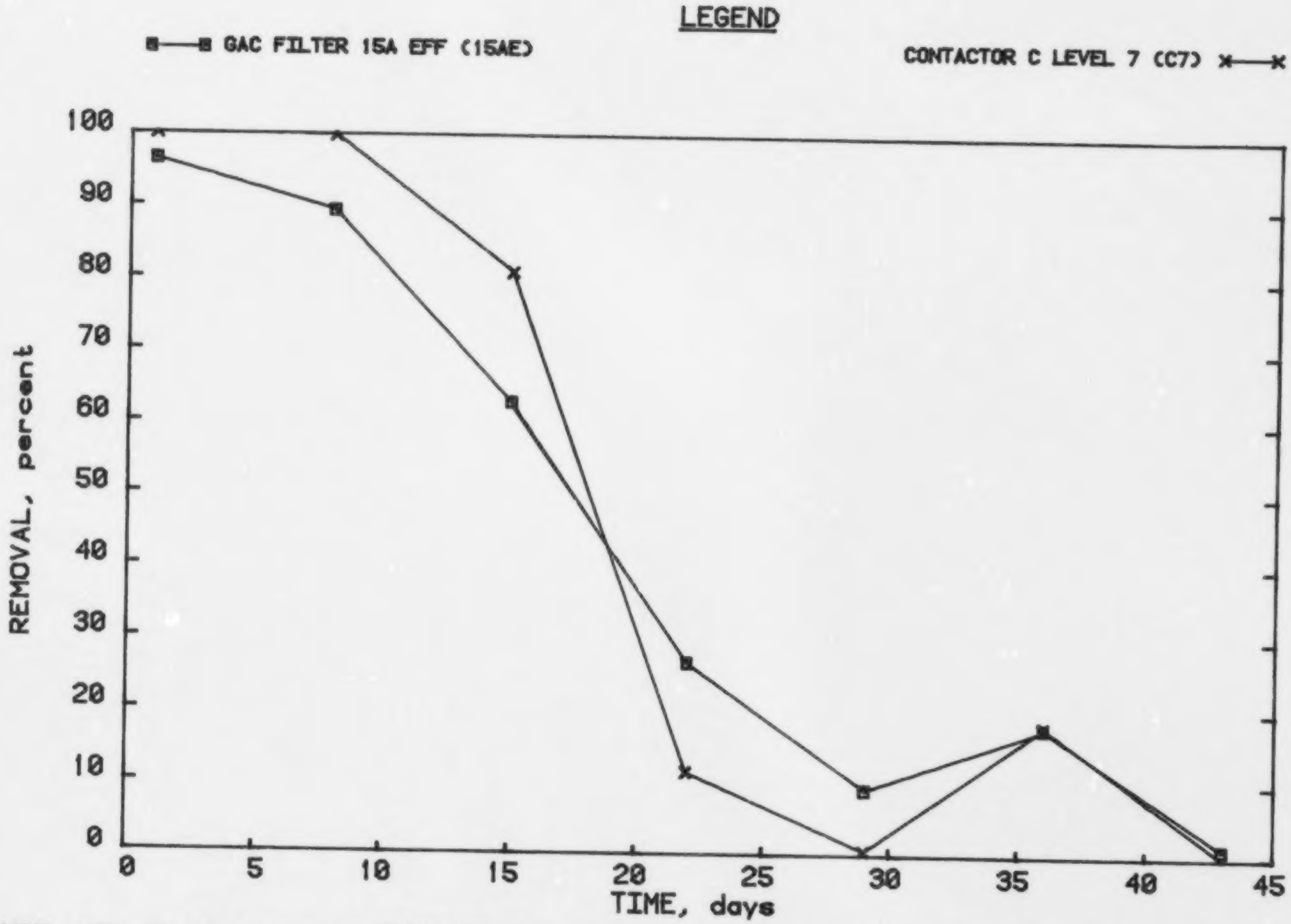


FIGURE 50. Instantaneous THM (ITTT) percent removal curves for GAC Filter 15A effluent and Contactor C level 7, Phase 3-1.

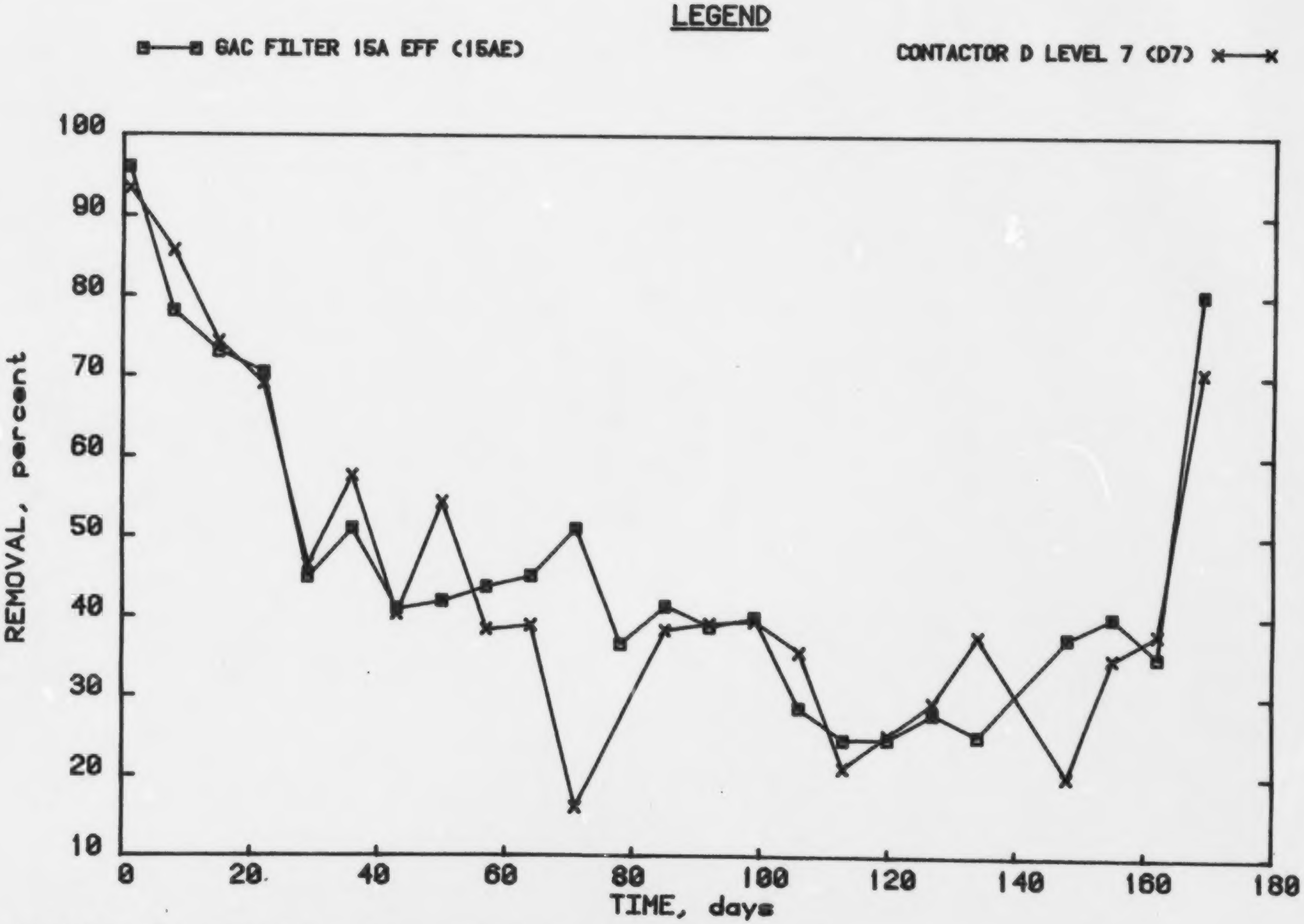


FIGURE 51. THM formation potential (FTTT) percent removal curves for GAC Filter 15A effluent and Contactor D level 7, Phase 3-0.

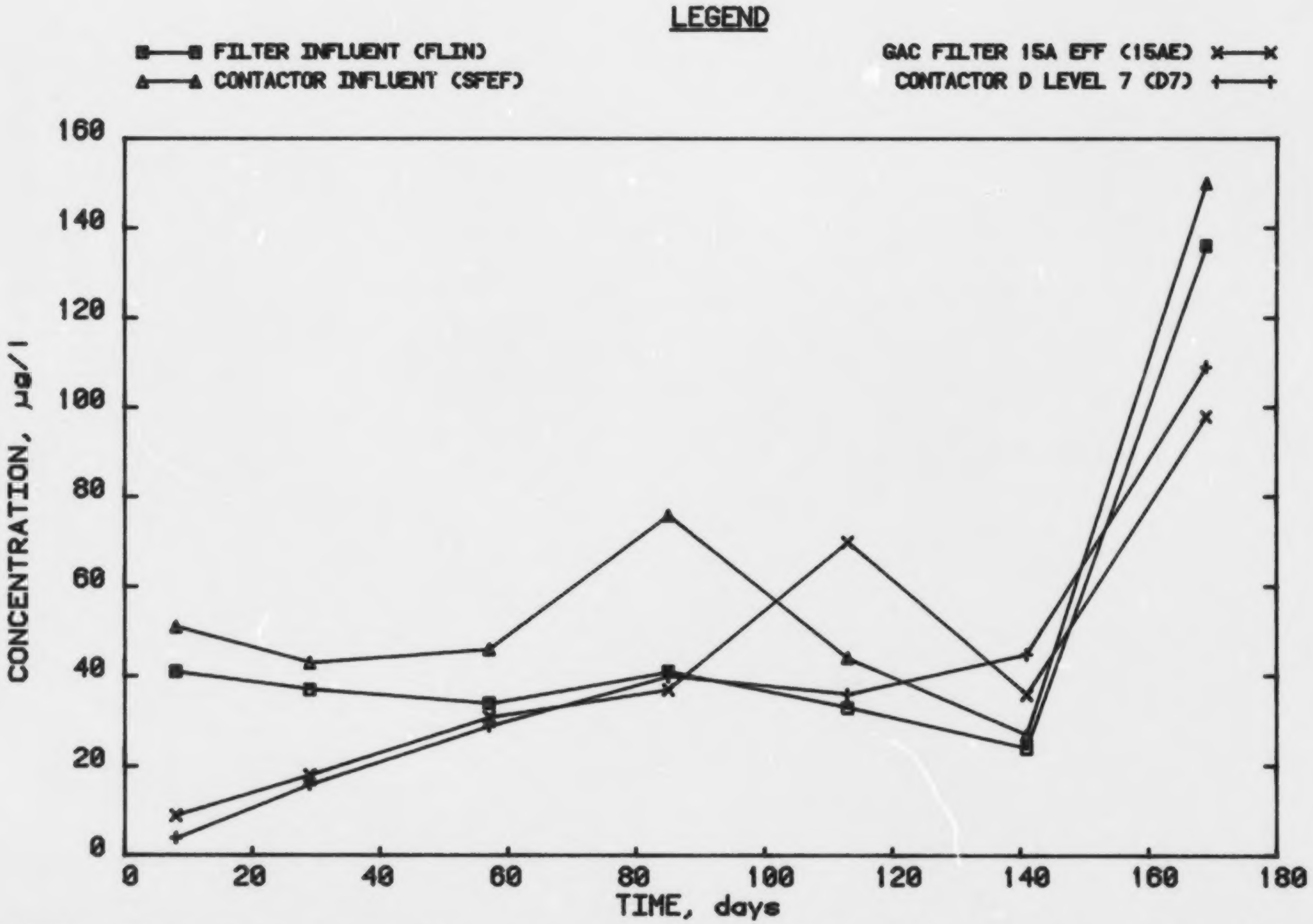


FIGURE 52. Carbon adsorbable organohalides (CAOX) breakthrough curves for GAC Filter 15A effluent and Contactor D level 7, Phase 3-0.

TABLE 40. PURGEABLE HALOGENATED ORGANICS FOR CONTACTOR D LEVEL 7 AND GAC FILTER 15A EFFLUENT, PHASE 3-0

	Influent			15AE			Influent			D7		
Parameter	Min Value (µg/l)	Max Value (µg/l)	Avg Value (µg/l)	Min Value (µg/l)	Max Value (µg/l)	Avg Value (µg/l)	Min Value (µg/l)	Max Value (µg/l)	Avg Value (µg/l)	Min Value (µg/l)	Max Value (µg/l)	Avg Value (µg/l)
Carbon tetrachloride	a	0.2	0.0	a	a	a	a	0.2	0.0	a	a	a
1,2-Dichloroethane	a	a	a	a	a	a	a	a	a	a	a	a
1,1,1-Trichloroethane	a	0.2	0.1	a	0.2	0.0	a	0.2	0.0	a	0.2	0.0
Dichloromethane	0.2	0.6	0.2	a	0.6	0.2	a	0.6	0.2	a	0.5	0.2
Tetrachloroethylene	a	0.2	0.1	a	a	a	a	0.2	0.1	a	a	a
Trichloroethene	a	0.2	0.1	a	0.2	0.0	a	0.2	0.1	a	a	a
Chlorobenzene	a	0.2	0.0	a	a	a	a	0.2	0.0	a	a	a
o-Dichlorobenzene	a	0.2	0.1	a	a	a	a	0.2	0.0	a	0.2	0.0

[a] Not Detected.

TABLE 41. PURGEABLE HALOGENATED ORGANICS FOR CONTACTOR C LEVEL 7 AND GAC FILTER 15A EFFLUENT, PHASE 3-1

	Influent			15AE			Influent			C7		
Parameter	Min Value (μg/l)	Max Value (μg/l)	Avg Value (μg/l)	Min Value (μg/l)	Max Value (μg/l)	Avg Value (μg/l)	Min Value (μg/l)	Max Value (μg/l)	Avg Value (μg/l)	Min Value (μg/l)	Max Value (μg/l)	Avg Value (μg/l)
Carbon tetrachloride	a	a	a	a	a	a	a	a	a	a	a	a
1,2-Dichloroethane	a	a	a	a	a	a	a	a	a	a	a	a
1,1,1-Trichloroethane	a	a	a	a	a	a	a	a	a	a	a	a
Dichloromethane	a	a	a	a	a	a	a	a	a	a	0.2	0.0
Tetrachloroethylene	a	0.2	0.0	a	a	a	a	0.2	0.0	a	a	a
Trichloroethene	a	0.2	0.1	a	a	a	a	0.2	0.1	a	a	a
Chlorobenzene	a	a	a	a	a	a	a	a	a	a	a	a
o-Dichlorobenzene	a	a	a	a	a	a	a	a	a	a	a	a

[a] Not Detected.

TABLE 42. PURGEABLE NON-HALOGENATED ORGANICS FOR CONTACTOR D LEVEL 7 AND GAC FILTER 15A EFFLUENT, PHASE 3-0

	Influent			15AE			Influent			D7		
Parameter	Min Value (μg/l)	Max Value (μg/l)	Avg Value (μg/l)	Min Value (μg/l)	Max Value (μg/l)	Avg Value (μg/l)	Min Value (μg/l)	Max Value (μg/l)	Avg Value (μg/l)	Min Value (μg/l)	Max Value (μg/l)	Avg Value (μg/l)
Benzene	0.2	1.4	0.4	0.2	0.9	0.3	a	1.2	0.3	0.2	0.8	0.3
o-Xylene	a	a	a	a	a	a	a	a	a	a	a	a
Ethylbenzene	a	20.8	1.9	a	2.4	0.3	a	13.4	1.7	a	0.8	0.1
Toluene	a	1.8	0.5	0.2	2.2	0.5	a	1.2	0.4	0.2	2.8	0.4
Hexane	a	1.1	0.1	a	1.2	0.1	a	1.5	0.2	a	1.0	0.1
Tetralin	a	1.2	0.1	a	1.2	0.1	a	2.4	0.1	a	0.9	0.0

[a] Not Detected.

TABLE 43. PURGEABLE NON-HALOGENATED ORGANICS FOR CONTACTOR C LEVEL 7 AND GAC FILTER 15A EFFLUENT, PHASE 3-1

	Influent			15AE			Influent			C7		
Parameter	Min Value (μg/1)	Max Value (μg/1)	Avg Value (μg/1)	Min Value (μg/1)	Max Value (μg/1)	Avg Value (μg/1)	Min Value (μg/1)	Max Value (μg/1)	Avg Value (μg/1)	Min Value (μg/1)	Max Value (μg/1)	Avg Value (μg/1)
Benzene	0.2	0.7	0.4	0.2	0.4	0.2	0.2	1.0	0.6	0.2	0.6	0.4
o-Xylene	a	a	a	a	a	a	a	0.2	0.0	a	0.2	0.0
Ethylbenzene	a	0.6	0.1	a	0.2	0.0	a	0.2	0.0	a	0.2	0.1
Toluene	a	0.4	0.2	a	a	a	a	0.9	0.2	a	0.2	0.0
Hexane	a	0.2	0.1	a	a	a	a	0.6	0.2	a	0.7	0.1
Tetralin	a	a	a	a	a	a	a	a	a	a	a	a

a = Not Detected.

Acid extract GC/FID profiles were performed on samples from 15AE and D7, Phase 3-0. Figures 53 through 56 are the profiles after one week, three months, four months and five months of operation, respectively. These profiles enable a comparison of the two similar EBCT systems and also a comparison of what the consumer would receive with and without GAC treatment.

Figure 53 shows that the GAC in both systems was effectively removing organics after one week of operation. This is evidenced by the lesser number of peaks and by lesser peak heights at the same retention time. It appears that D7 was adsorbing more effectively than 15AE during the first half of the chromatogram. This difference may be due to slight variations in detector response. The last third of the chromatogram for D7 shows peaks of greater magnitude than 15AE. Three possible explanations for this are: 1) the peaks were real since they are present to some extent in the influent; 2) they were picked up during the concentration procedure since they are present to some extent in the solvent blank; or 3) the contactor liner was leaching organics. Therefore, 15AE and D7 were similar in their performance after one week of operation.

The third month of operation (Figure 54) shows an improvement in the quality of the influent water when compared to the first week (Figure 53). The GAC effluents also appear to be improved when compared to the effluents after one week of operation. The GAC was not effective in removing organics present in the first third of the chromatogram. After the first third of the chromatogram, the GAC became effective in removing organics. The last third of the D7 chromatogram shows more peaks of greater magnitude similar to those observed in Figure 53. Except for this section of the chromatogram, 15AE and D7 were similar in their performance after three months of operation.

The performance of the two GAC systems after four months of operation is presented in Figure 55. The figure shows a significant difference between 15AE and D7 during the first third of the chromatogram. It appears that while D7 was still removing organics, 15AE was starting to desorb organics. During the rest of the chromatogram, both GAC systems continued to remove peaks observed in the influent. The last third of the chromatogram for D7 does not show the peaks observed earlier. This tends to support the hypothesis that the contactor liner was leaching organics. Overall, the performance of 15AE and D7 no longer appear to be similar after four months of operation.

The performance of the two GAC systems after five months of operation is presented in Figure 56. During the first third of the chromatogram, some desorption was occurring in both GAC systems. Both GAC systems were still removing organics after the first third of the chromatogram. Once again, 15AE and D7 were very similar in their performance after five months of operation.

Attempting to use acid extract GC/FID profiles to compare the two similar EBCTs from two different GAC systems has pointed out the fact that, in this case, a rigid comparison is not really possible. For example, it is

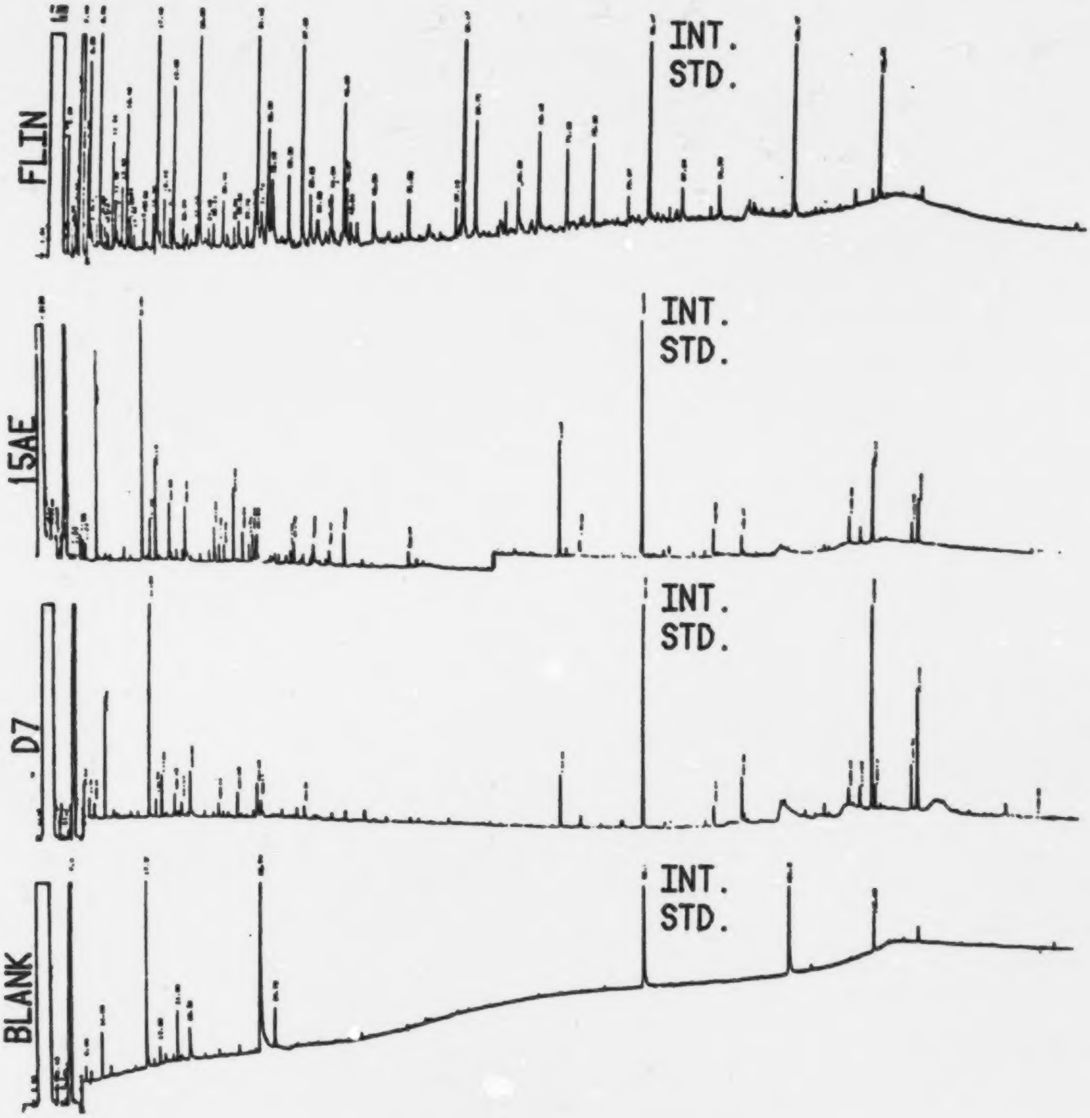


FIGURE 53. Acid extract profiles for filter influent, GAC Filter 15A effluent and Contactor D level 7, Phase 3-0, runday eight.

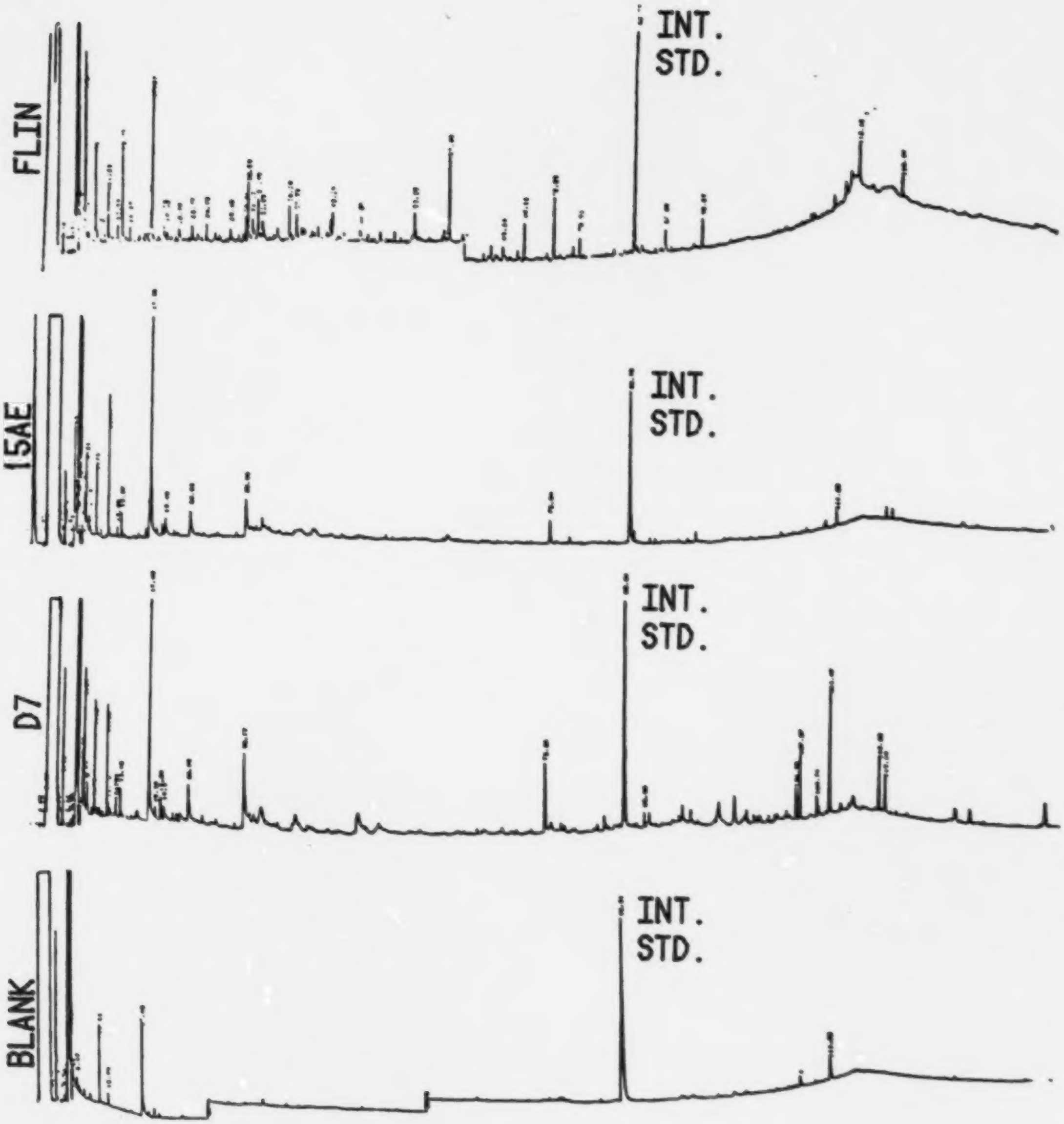


FIGURE 54. Acid extract profiles for filter influent, GAC Filter 15A effluent and Contactor D level 7, Phase 3-0, runday 85.

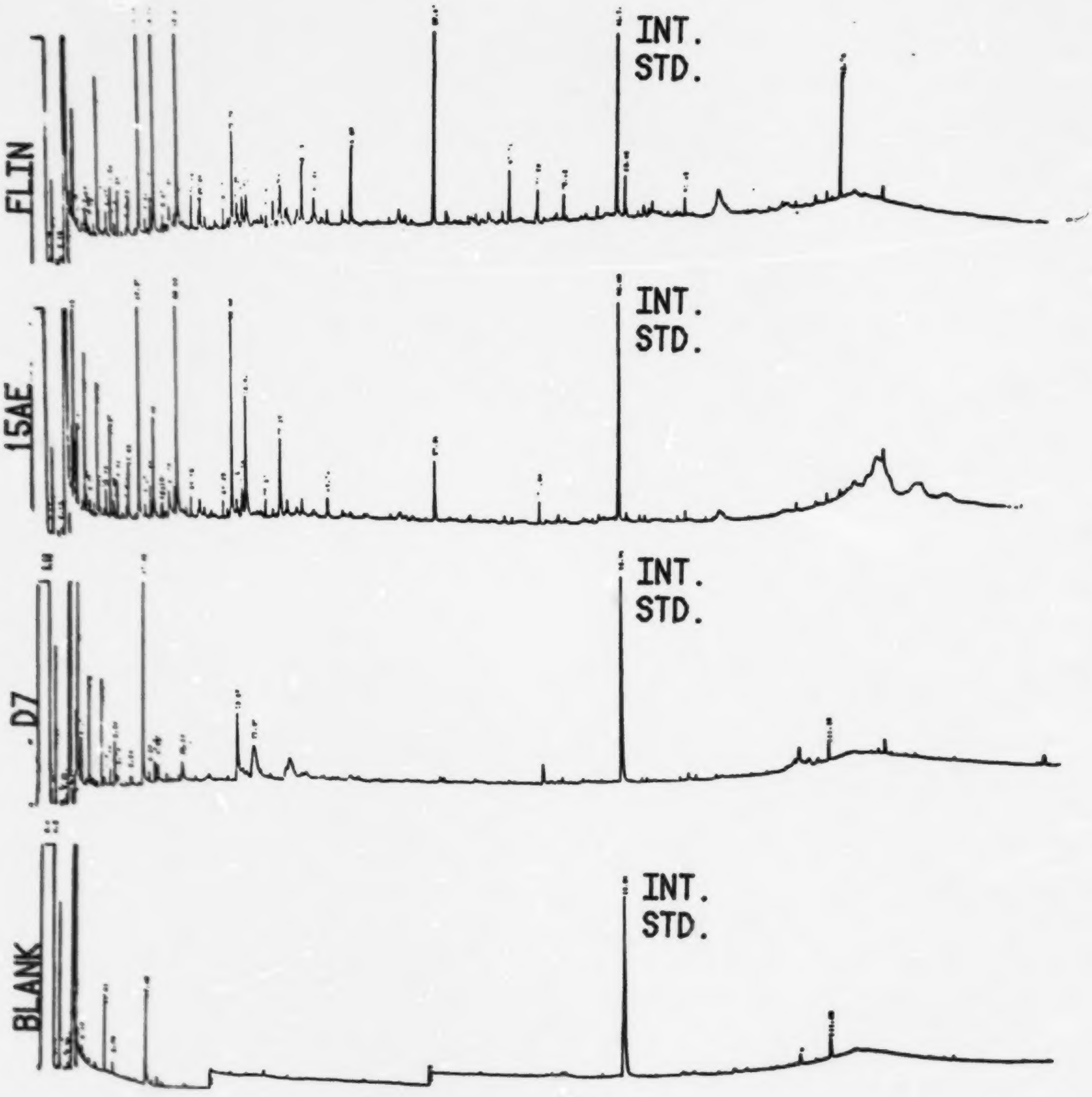


FIGURE 55. Acid extract profiles for filter influent, GAC Filter 15A effluent and Contactor D level 7, Phase 3-0, runday 113.

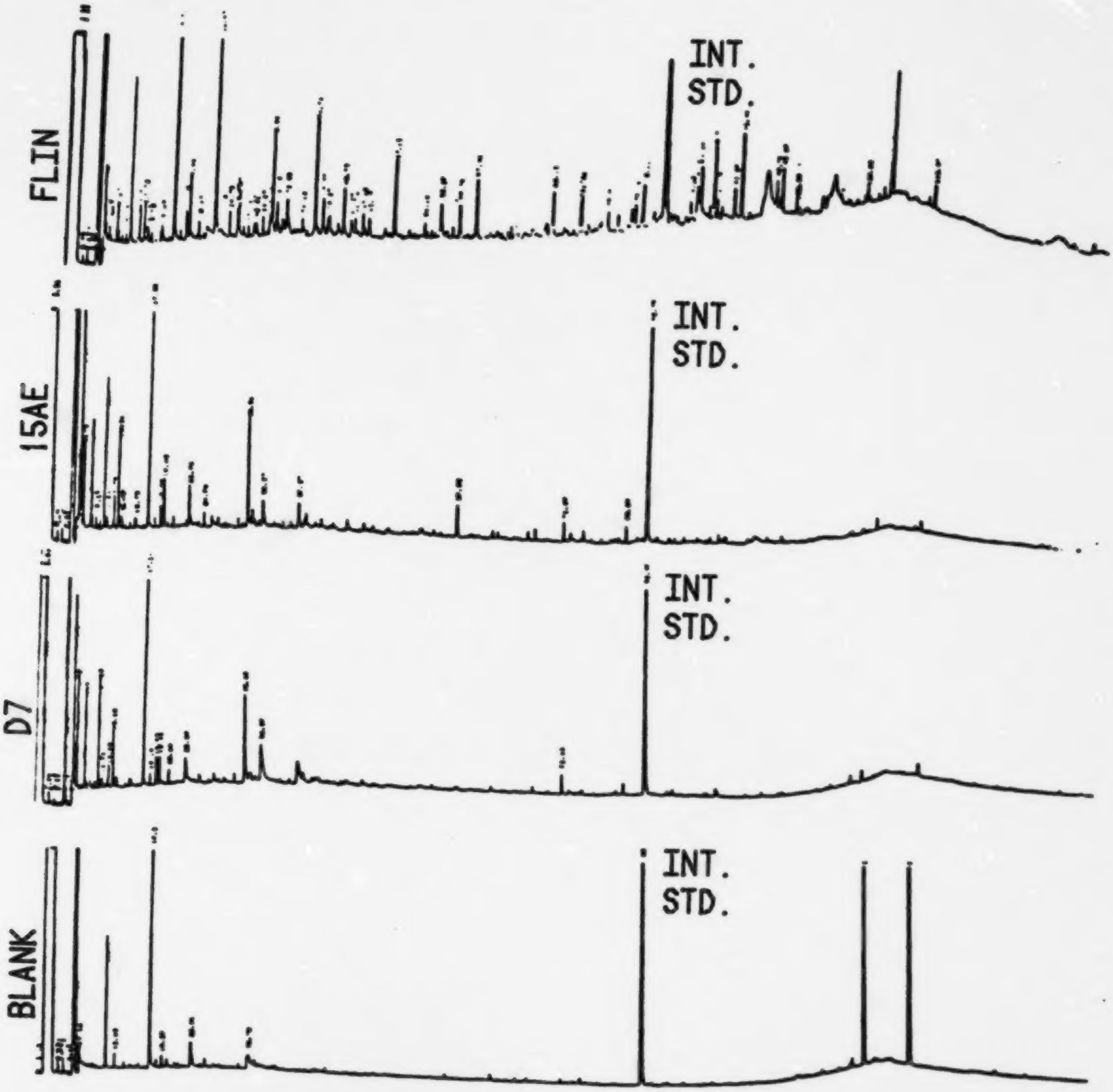


FIGURE 56. Acid extract profiles for filter influent, GAC Filter 15A effluent and Contactor D level 7, Phase 3-0, runday 141.

possible to have desorption occuring in one system and not in the other at the time of sample collection as observed in Figure 55. This would cause one to conclude that the two systems were not performing equally. However, the next samples, collected one month later, showed the two systems to be equal. In order to obtain a more accurate comparison, it would be necessary to have more frequent sampling. Following this consideration and assuming that the peaks observed in the first two D7 samples during the latter third of the chromatogram were due to the leaching of contactor liner, it would appear that 15AE and D7 performed similarly.

The percent of occurrence of GC/MS tentatively identified compounds for the acid extracts from GAC Filter 15A can be found in Table 44. The results from D7 will be discussed later in this objective with the Contactor D results. The results in the table deal only with the percent of occurrence of the compounds and not their concentrations. Accordingly, use of these data in discussing the ability of GAC to remove these compounds is difficult. The following points should be taken into consideration when examining these data with respect to removal by GAC:

1. Only compounds with a high percent of occurrence should be examined. In this case a high percent of occurrence will be defined as 30% or greater.
2. Compounds which have a high percent of occurrence in the influent and not in the effluent are not necessarily well adsorbed by GAC. Given the limits of detection of the GC/MS, it is possible that the concentration of the influent was just sufficient for the GC/MS to identify while the effluent concentration was not.
3. Compounds with a higher percent of occurrence in the effluent than in the influent could be due to either the limit of detection explained above or desorption of the compound from the GAC.

Table 44 shows that of the 46 compounds identified, only seven had a high percent of occurrence. Of these, 1,3,5-trimethyl-1,3,5-triazine-2,4,6-(1H,2H,3H)-trione, nitrobenzene and 3,3,3-trichloro-1-propene appeared to be well adsorbed by the GAC, while 2,H-pyran-2-one,2-cyclohexene-1-one, dibromochloromethane, 7-oxabicyclo[4.0.1]heptane and 2,H-pyran-2-one varied from marginal to only slightly adsorbed. Compounds identified in the blank which would negate their identification in the samples included diethyl ester-1,2-benzenedicarboxylic acid, 2-cyclahexene-1-ol and 3,3-dimethylhexane. The other 36 compounds occurred too infrequently to draw any conclusions as to the ability of GAC to adsorb them given the above considerations.

Breakthrough and percent removal graphs show the two GAC systems with similar EBCTs to be equivalent. Next, in order to compare the operating condition of the two systems, it was necessary to select exhaustion criteria for various parameters. Arbitrary exhaustion criteria were selected for TOC, INST $CHCl_3$, INST $CHBrCl_2$, THMFP and THMSIMDIST, thus covering individual organic compounds, groups of specific and non-specific organic compounds.

TABLE 44. ACID EXTRACT COMPOUNDS TENTATIVELY IDENTIFIED BY GC/MS FROM GAC FILTER 15A

Compound	Percent of Occurrence[a]		
	FLIN	15AE	Blank
1,3,5-Trimethyl-1,3,5-triazine-2,4,6-(1H,2H,3H)-trione	90	20	10
Dibromochloromethane	60	50	b
Nitrobenzene	50	b	b
3,3,3-Trichloro-1-propene	50	b	b
2-Cyclohexene-1-one	40	30	10
7-Oxabicyclo(4.0.1)heptane	40	40	10
2,H-Pyran-2-one	30	10	b
Diethyl ester-1,2-benzenedicarboxylic acid	20	10	20
3-Penten-2-one	20	b	b
1-Pentyne	20	10	b
Butyl-2-methyl propylester-1,2-benzenedicarboxylic acid	10	20	b
1-Chloro-2-butene	10	20	b
1,4-Dichlorobenzene	b	20	b
Benzoic acid	10	b	b
2-Butene	10	b	b
Carbon tetrachloride	10	b	b
6-Chloro-N-ethyl-(1H ethylmethyl)-1,3,5-triazine	10	b	b
Cyclohexane	10	10	b
2-Cyclohexene-1-ol	10	b	10
Dibutyl ester ethanoic acid	10	b	10
2,2-Dimethylbutanal	10	b	b
2,3,-Dimethyl-1-butene	10	b	b
4,4-Dimethyl-1-pentene	10	b	b
1,4-Dinitropentane	10	b	b
3,4-Epoxy-2-hexanol	10	b	b
3-Ethyl-4-methylfurandiene	10	b	b
3-Methyl-2-butadiene	10	b	10
2-Methyl-1,4-dinitrobenzene	10	b	b
2-Nitropropane	10	b	b
Tribromomethane	10	b	b
Tributyl ester phosphoric acid	10	b	b
Triethylborane	10	b	b
4,4,5-Trimethyl-2-hexene	10	b	b
2,2,3-Trimethylpentane	10	b	b
Bromocyclohexane	b	10	b
1,3,5-Cycloheptatriene	b	10	b
Cyclohexene	b	10	b
1,4-Dichlorobutane	b	10	b
1-Ethyl-2-methylbenzene	b	10	b
2-Hexen-3-one	b	10	10
1,7-Octadiene	b	10	b
Pentadinitrile	b	10	b
2-Pentanone	b	10	b
Trimethylborane	b	10	10
2,2,5-Trimethylhexane	b	10	b
3,3-Dimethylhexane	b	b	10

[a] Based on ten samples.
[b] Not detected.

The criteria and results for 15AE and D7, Phase 3-0, can be found in Table 45 and for 15AE and C7, Phase 3-1, in Table 46. The service times, or length of operations, for all exhaustion criteria defined were identical except for INST $CHBrCl_2$ in Phase 3-1 where C7 would have been kept on-line one week longer. Thus, the two systems performed identically based on a single point comparison. The carbon use rates for the two GAC systems were similar with the GAC filter performing slightly better. The mass loading values were similar except for INST $CHCl_3$ and INST $CHBrCl_2$ and to a certain extent THMFP. These differences in loading were probably due to the differences in INSTTHM concentrations previously discussed. The effect of varying temperature and influent concentrations on service time and the carbon use rate is readily apparent by comparing Tables 45 and 46. Table 45 represents lower temperatures and, therefore, lower $CHCl_3$, $CHBrCl_2$ and THMSIMDIST concentrations which resulted in significantly longer service times and lower carbon use rates. The influent TOC and THMFP concentrations in Table 45 represent the lower concentrations and, therefore, the longer service times and carbon use rates. Although the carbon use rates and service times are significantly different between Tables 45 and 46, the mass loadings were similar except where desorption was occurring.

It is apparent that there was no major difference in adsorptive behavior between GAC filters and contactors with a similar EBCT. Thus, the GAC filters acting as a filter for carryover solids had little apparent effect on the GAC performance as an adsorbent material for dissolved organics.

Effect of Various Contact Times--

The improved quality of water achieved by increased EBCT is shown by the EBCT breakthrough curves for Contactor D, Phase 3-0, for INST $CHCl_3$, INST $CHBrCl_2$, TOC, THMFP, THMSIMDIST and organohalides in Figures 57 through 62, respectively. Further evaluation of the breakthrough curves is possible by selecting various effluent exhaustion criteria and comparing the carbon use rates for the various EBCTs. It should be noted that only systems which remained in service long enough to fulfill the exhaustion criteria are included in the following discussion. Lower carbon use rates would have resulted had this data been available.

Effluent exhaustion criteria of 5 µg/l for INST $CHCl_3$, 1 µg/l for INST $CHBrCl_2$ and 1,000 µg/l for TOC were selected. Exhaustion occurred when the effluent concentration exceeded a criterion and remained above it for at least three weeks. The exhaustion runday was then selected from the intersection of the horizontal criterion line and the breakthrough curve at or just before the first data point in the three-week set. Ideally, the carbon use rate should be calculated using parameters which have a constant concentration in the influent. However, this is not the case in full-scale systems where the influent concentration tends to fluctuate and follow seasonal trends. Thus, if the influent concentration is decreasing, the carbon use rates for the various EBCTs would tend to favor the longer contact times. The reverse of this is true when the influent concentration is increasing. Figure 63 presents a graph of the INST $CHCl_3$ carbon use rate for various

TABLE 45. EXHAUSTION CRITERIA FOR CONTACTOR D LEVEL 7 AND GAC FILTER 15A EFFLUENT, PHASE 3-0

	Exhaustion Criteria									
	TOC		CHC13		CHBrC12		THMFP		THMSIMDIST	
	1000 ug/1		5 ug/1		5 ug/1		100 u/gl		100 ug/1	
Parameter	15AE	D7	15AE	D7	15AE	D7	15AE	D7	15AE	D7
Service Time, days	57	57	64	64	148	148	57	57	169	169
GAC Use, kg/mil gal	153	164	136	146	59.2	63.0	153	164	51.8	55.5
Mass Load, gm/kg	24.2	22.9	0.07	0.16	0.04a	0.16	3.2	2.6	1.9	1.9
Percent Removal	30.5	19.6	- 1.4	51.5	51.3	48.1	43.8	38.4	16.2	14.9

a Desorption is occurring.

TABLE 46. EXHAUSTION CRITERIA FOR CONTACTOR C LEVEL 7 AND GAC FILTER 15A EFFLUENT, PHASE 3-1

	Exhaustion Criteria									
	TOC		CHCl3		CHBrCl2		THMFP		THMSIMDIST	
	1000 ug/l		5 ug/l		5 ug/l		100 u/gl		100 ug/l	
Parameter	15AE	C7	15AE	C7	15AE	C7	15AE	C7	15AE	C7
Service Time, days	22	22	15	15	29	36	29	29	36	36
GAC Use, kg/mil gal	410	429	604	628	310	259	310	324	249	260
Mass Load, gm/kg	20.6	21.0	0.29	0.37	0.17	0.23	2.7	2.4	1.6	1.5
Percent Removal	48.2	52.5	54.7	73.6	39.9	44.3	63.3	48.4	29.6	24.2

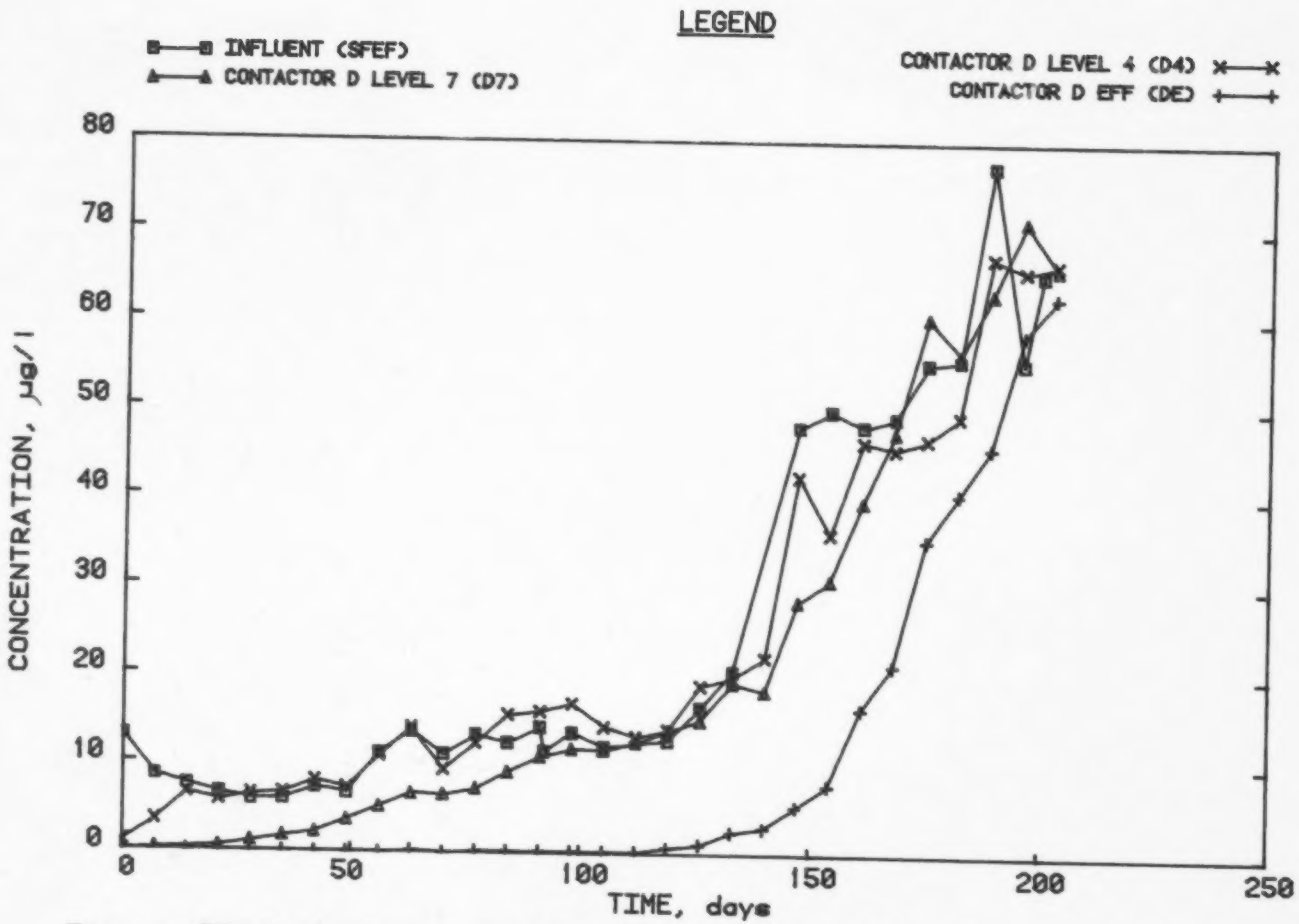


Figure 57. Instantaneous chloroform (ICLR) breakthrough curves for Contactor D, Phase 3-0.

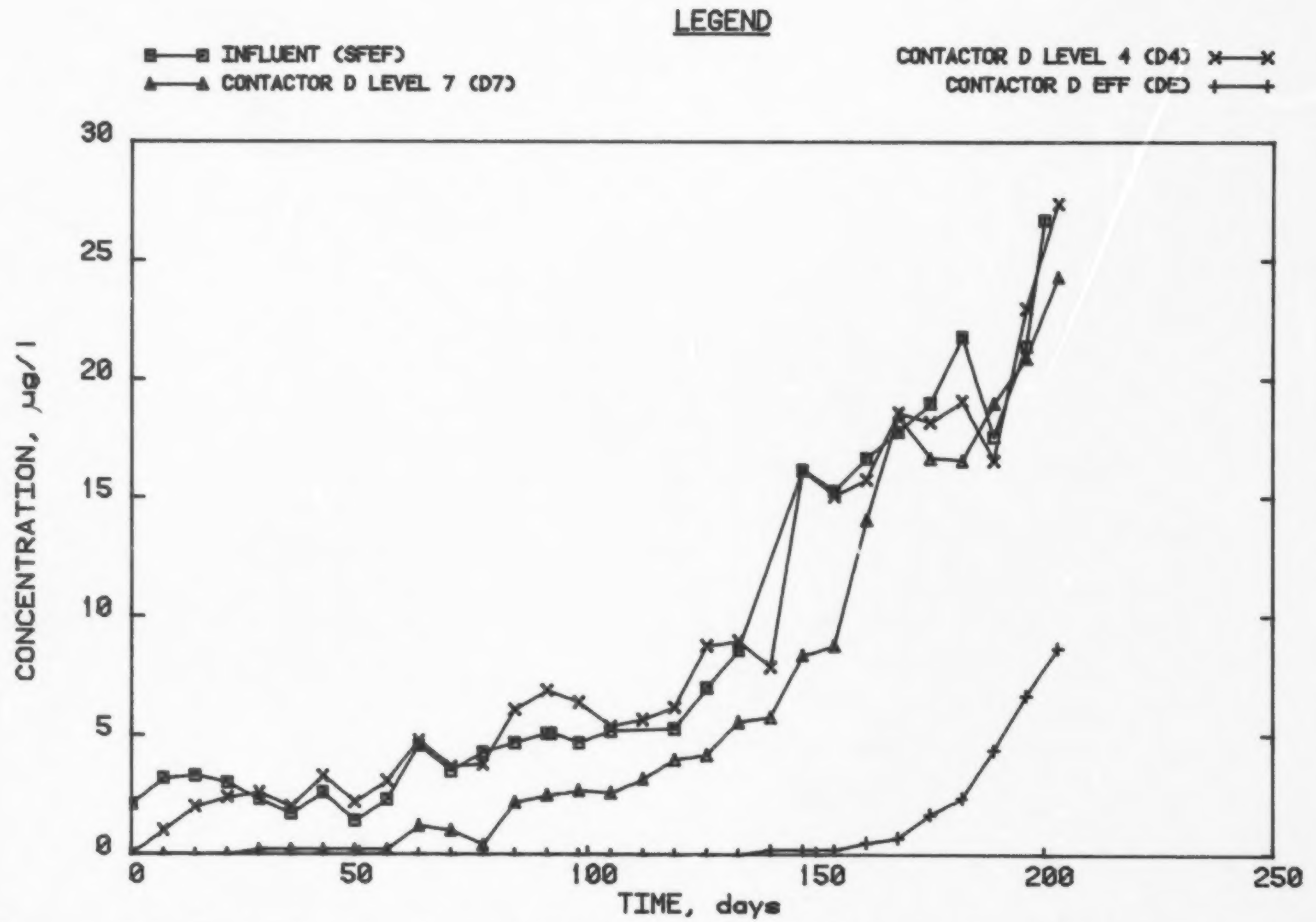


Figure 58. Instantaneous bromodichloromethane (ICL2) breakthrough curves for Contactor D, Phase 3-0.

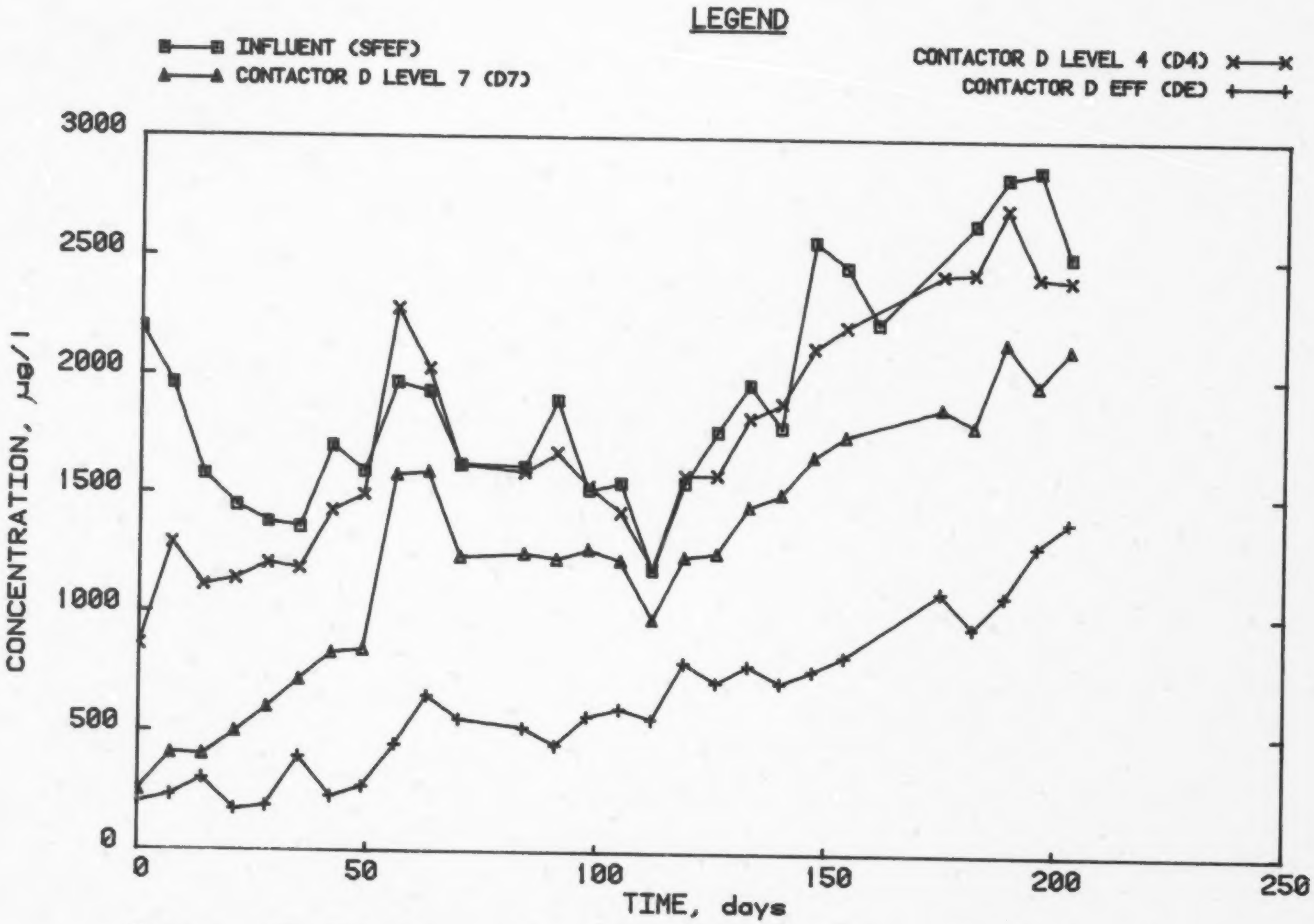


Figure 59. Total organic carbon (TOC) breakthrough curves for Contactor D, Phase 3-0.

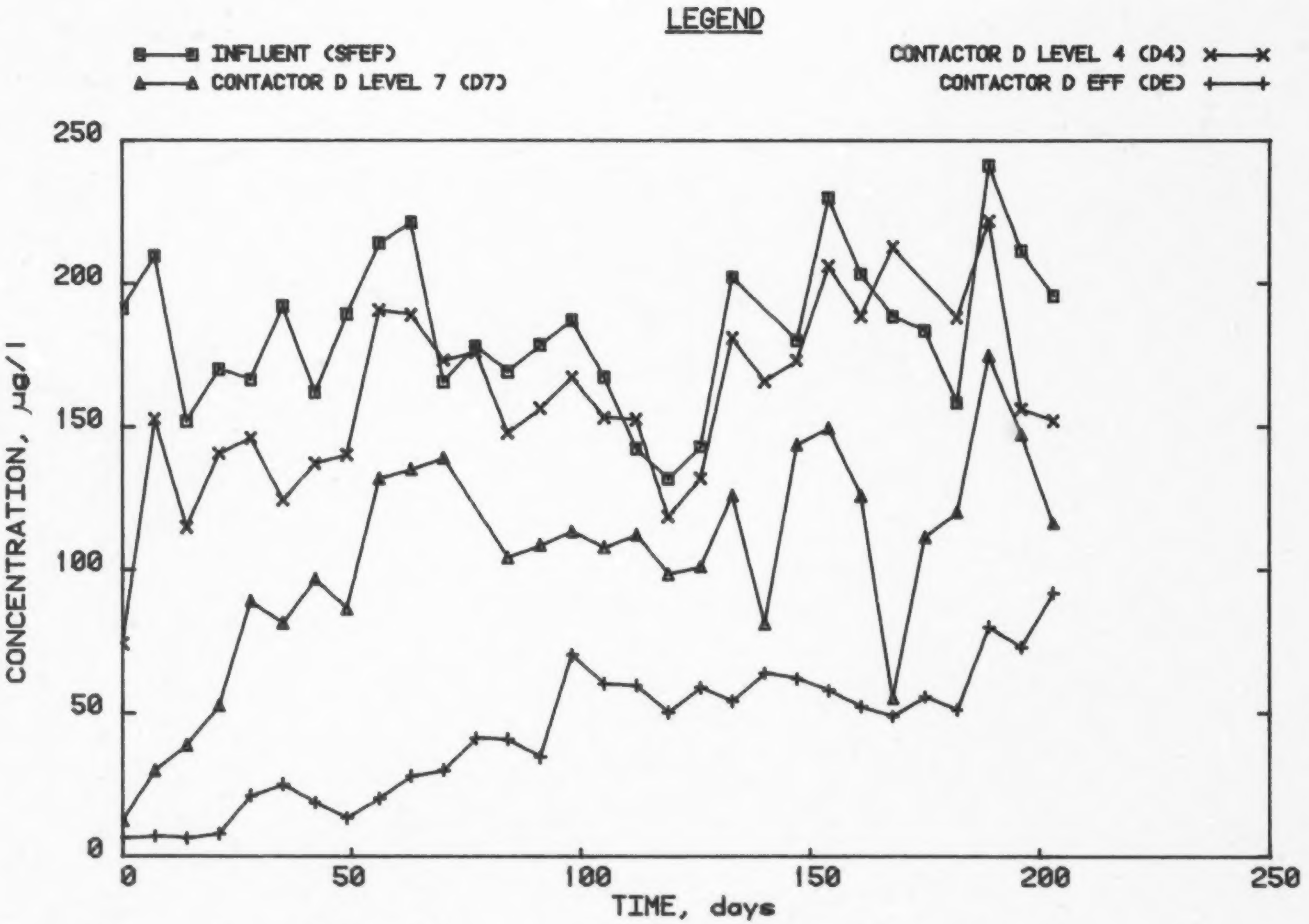


Figure 60. THM formation potential (FTTT) breakthrough curves for Contactor D, Phase 3-0.

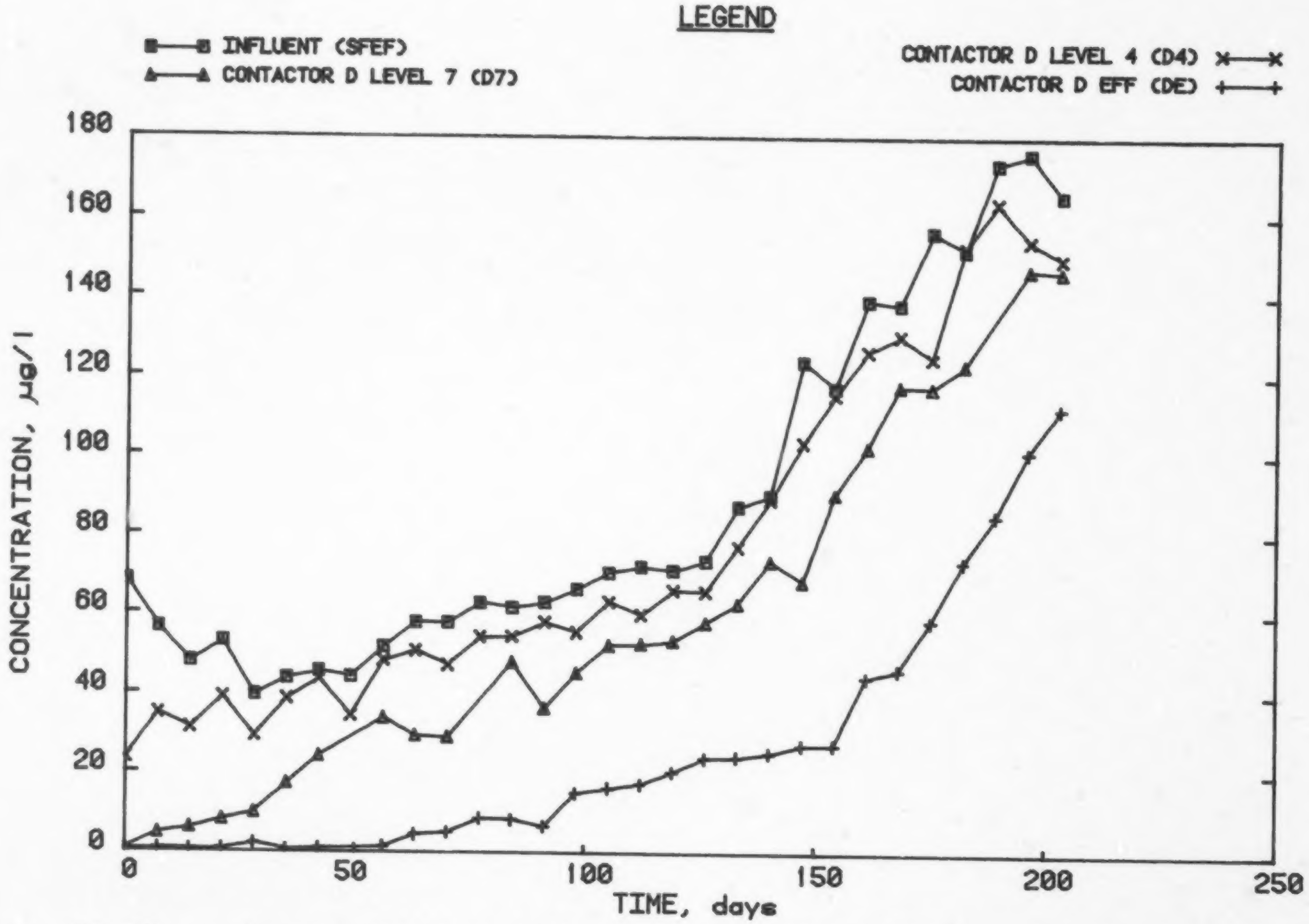


Figure 61. Three-day simulated distribution system THM (STT3) breakthrough curves for Contactor D, Phase 3-0.

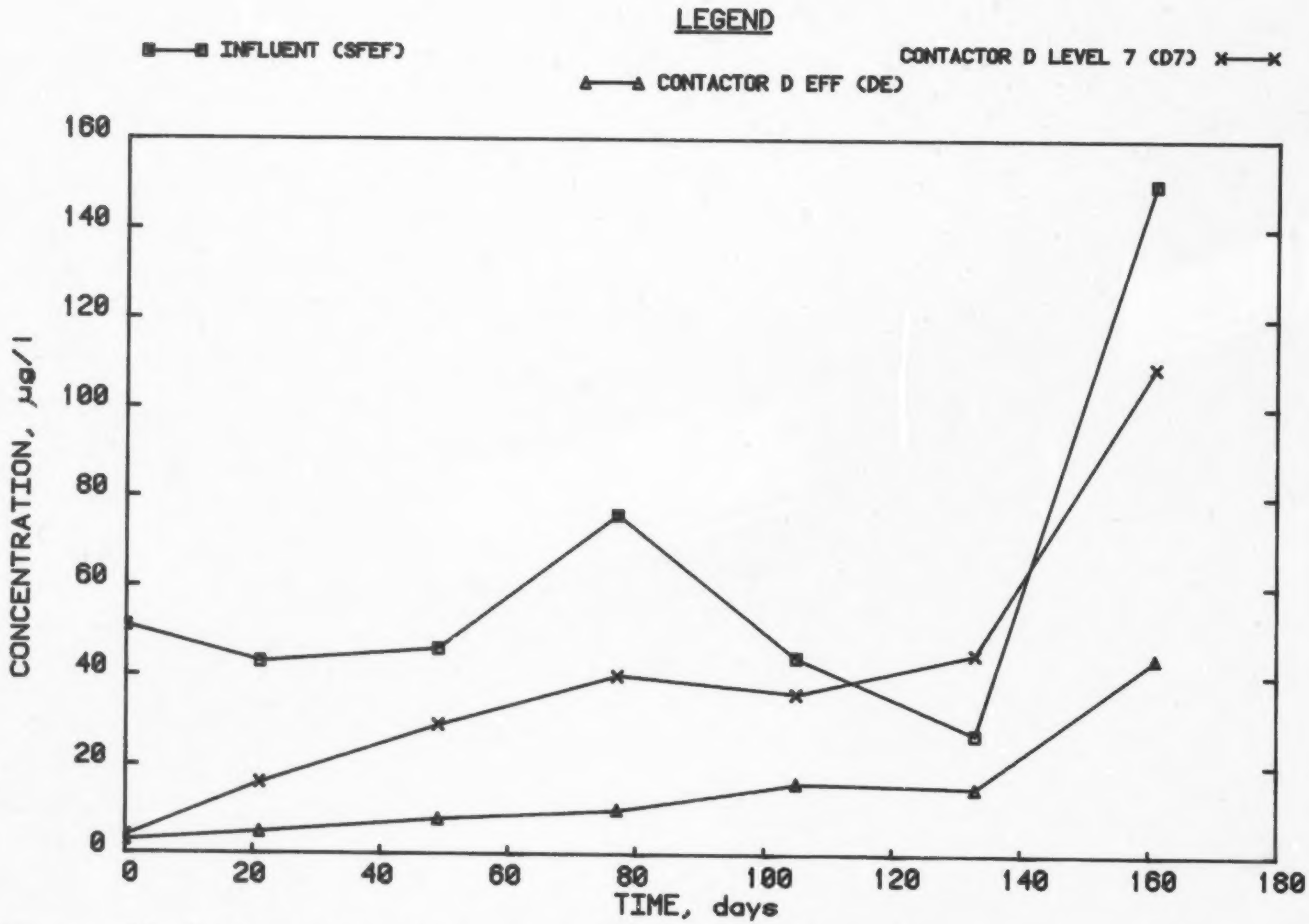


Figure 62. Carbon adsorbable organohalides (CAOX) breakthrough curves for Contactor D, Phase 3-0.

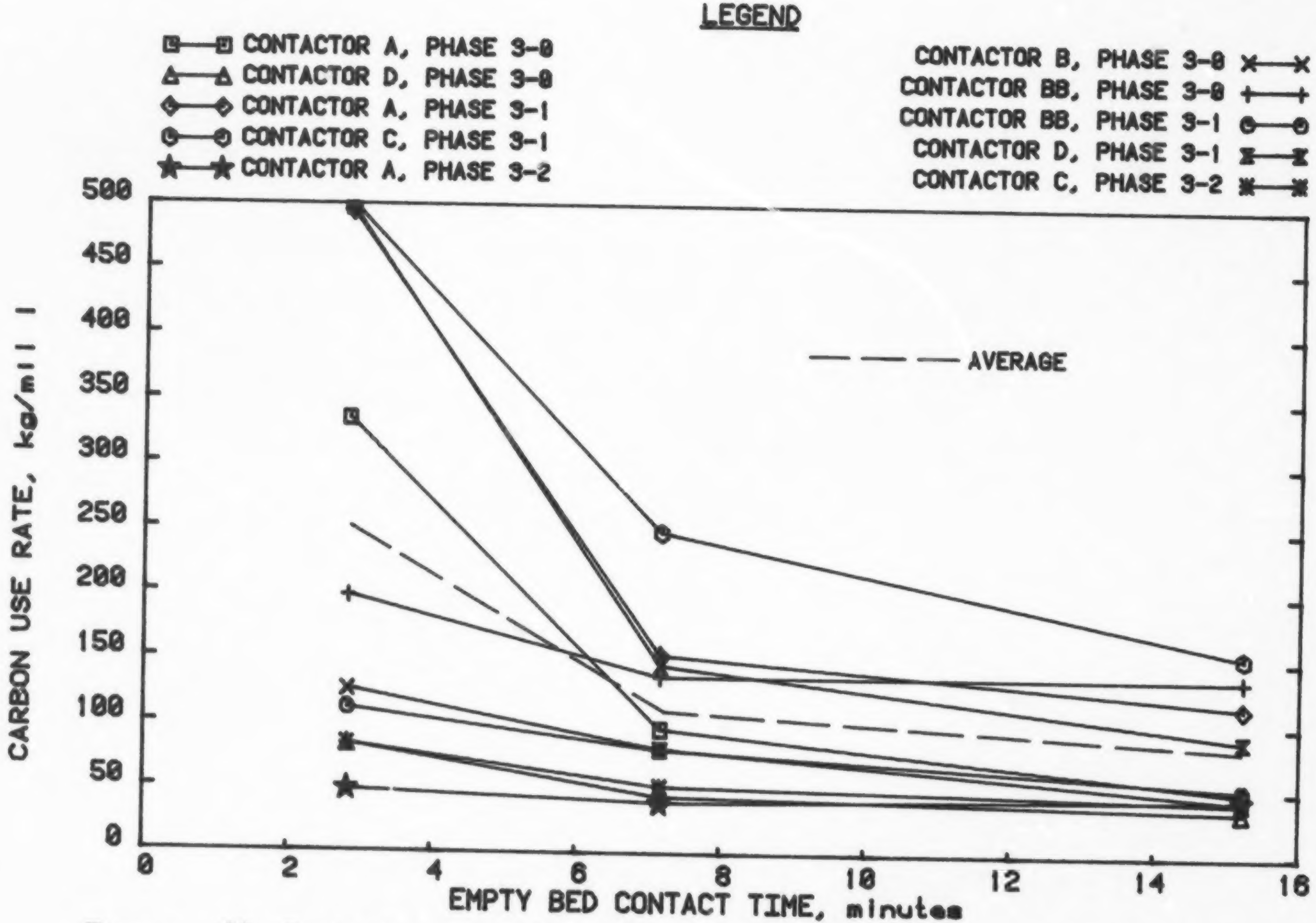


Figure 63. Instantaneous chloroform (ICLR) carbon use rates for multiple runs of contactors, Phase 3.

contactor runs against EBCT. From the figure, it is apparent that longer EBCTs do provide better utilization of the GAC. In order to discuss the effects of the changing influent concentrations, both increasing and decreasing influent concentrations were examined. Contactor A, Phase 3-1, represents a system which had a decreasing influent concentration and Contactor C Phase 3-2, represents a system with an increasing influent concentration. While both systems show varying carbon use rates, they also show that a longer EBCT provides a better GAC use rate.

The optimum EBCT for the majority of the systems appears to be between 7 and 15 minutes. However, the systems which came on line in August and September, or during the warmer water temperature months, appear to have an optimum EBCT somewhere beyond 15 minutes. Similar observations to the INST $CHCl_3$ results were found for INST $CHBrCl_2$ and TOC presented in Figures 64 and 65, respectively.

The effects of longer contact time on compounds represented by the acid profiles can be seen in Figures 66 and 67. Figure 66 presents a case where the influent contains many peaks of a large magnitude and Figure 67 an influent which contains few peaks of a large magnitude. In both cases, the GAC adsorbed the substances contained in the influent. It appears that longer contact time did not provide additional removal of the substances contained in the influent. However, longer contact times may provide additional protection from higher influent concentrations.

The percent of occurrence of GC/MS tentatively identified compounds for the acid extracts from Contactor D can be found in Table 47. The qualifiers listed in the GAC Filter 15A discussion also apply here. Table 47 shows that, of the 45 compounds identified, only seven had a high percent of occurrence, 30% or greater. Of these, dibromochloromethane, 3,3,3-trichloro-1-propene, 1,3,5-trimethyl-1,3,5-triazine-2,4,6-(1H,2H,3H)trione, nitrobenzene and tributyl ester phosphoric acid appeared to be well adsorbed while 2-cyclohexene-1-one and 7-oxabicyclo[4.0.2]heptane varied from marginal to not well adsorbed. Compounds identified in the blank which would negate their identification in the samples included dibutyl ester ethanoic acid and 2,2-proanyl chloride. The other 36 compounds occurred too infrequently to draw any conclusions as to the ability of GAC to adsorb them.

Grob CLSAs were performed on Contactor A influent and effluent samples, Phase 3-0, at startup and at approximately four week intervals thereafter for a total of eleven samples. Approximately 225 compounds were identified with an average of 106 on any one date and a range of 84 to 130 compounds. Except for the four THMs all concentrations were in the very low part per trillion or ng/l range. The health significance of these concentrations is unknown and is well beyond the scope and the intent of the project. In order to provide a point of perspective for these concentrations, Table 48 presents the MCLs which have been established, to date, for organic chemicals. The range of MCL concentrations is from 0.0002 to 0.1 mg/l. The average concentration of the non-THM compounds observed was well below 0.00001 mg/l (about 1/20 of the lowest MCL).

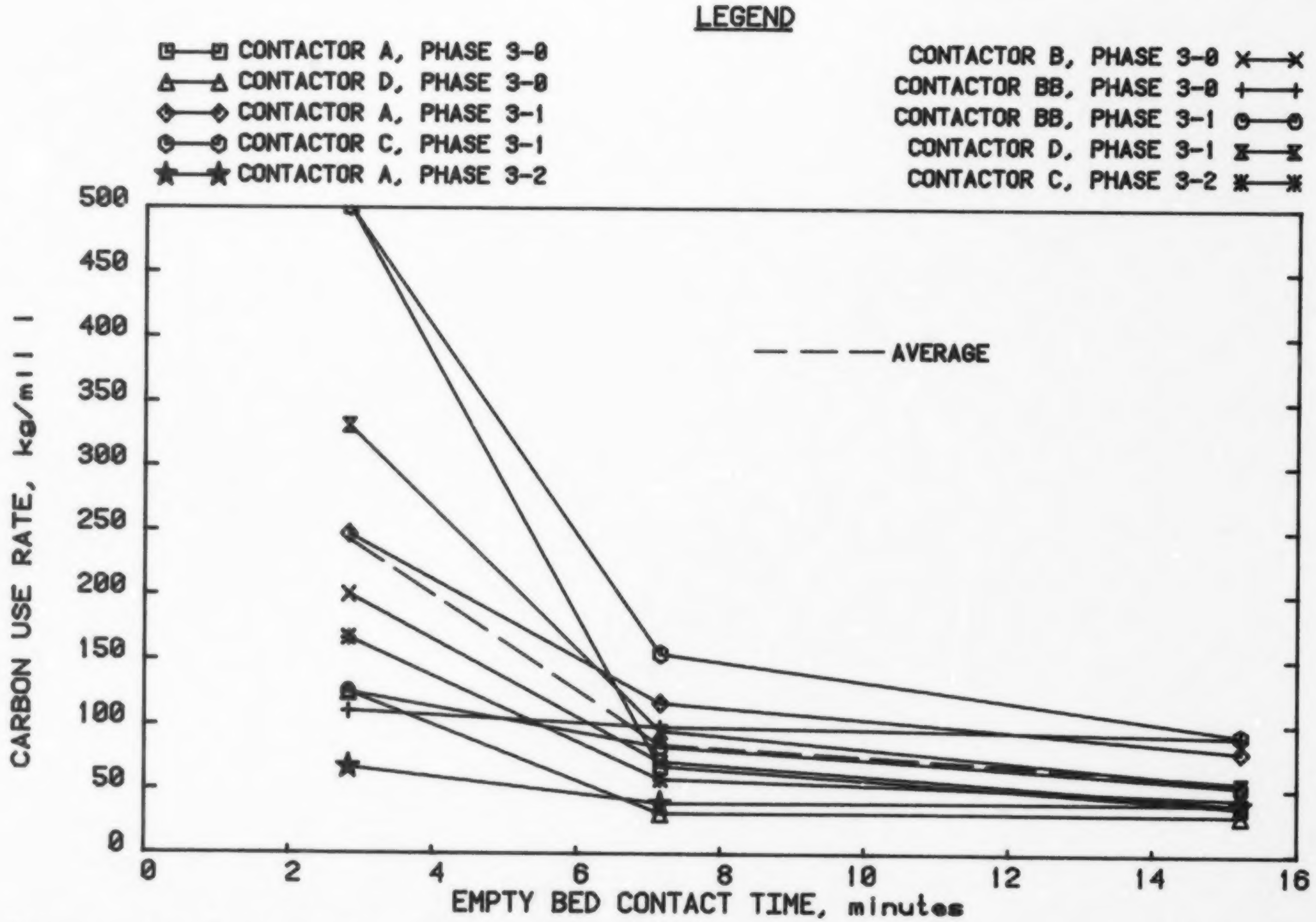


Figure 64. Instantaneous bromodichloromethane (ICL2) carbon use rates for multiple runs of contactors, Phase 3.

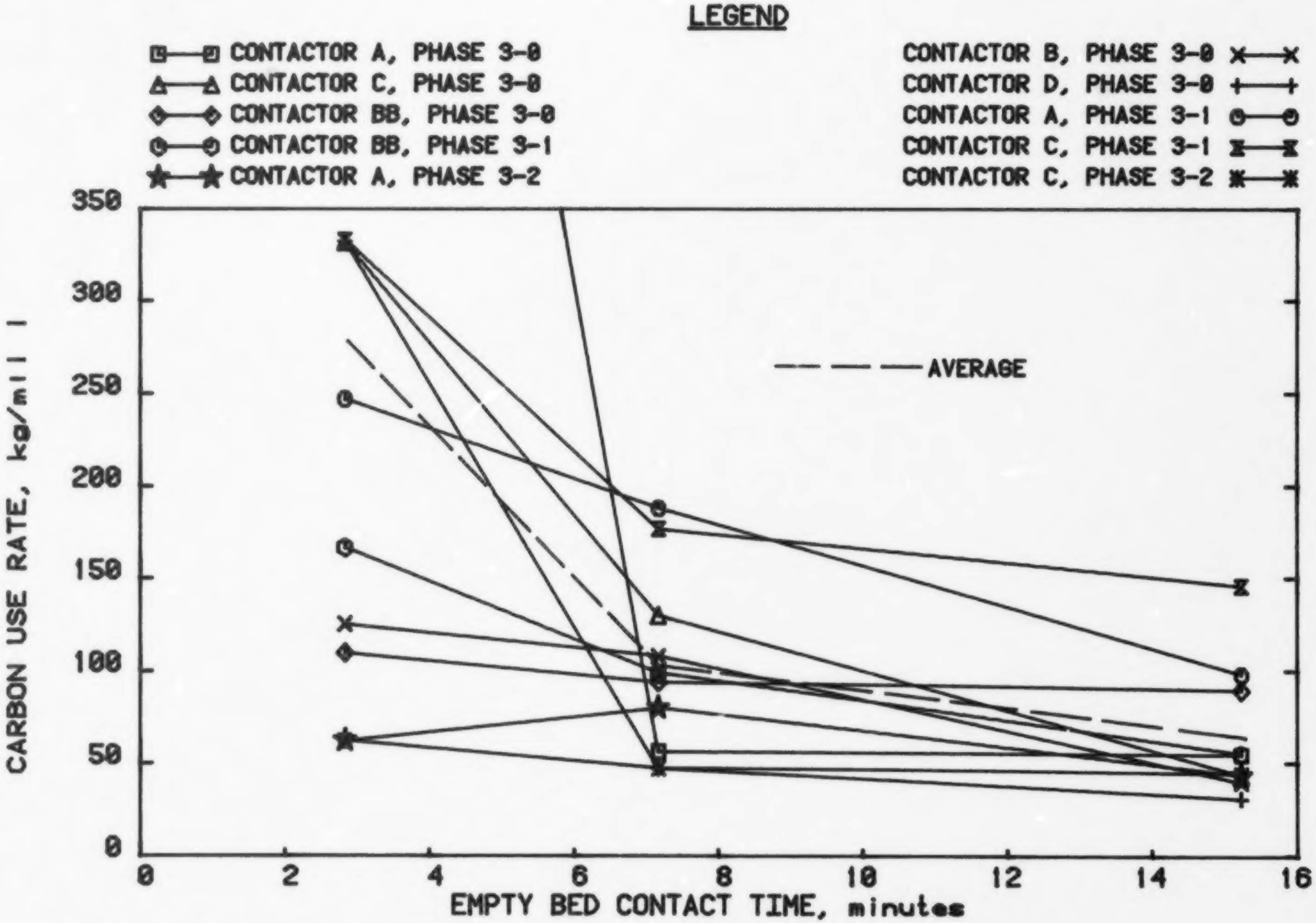


Figure 65. Total organic carbon (TOC) carbon use rates for multiple runs of contactors, Phase 3.

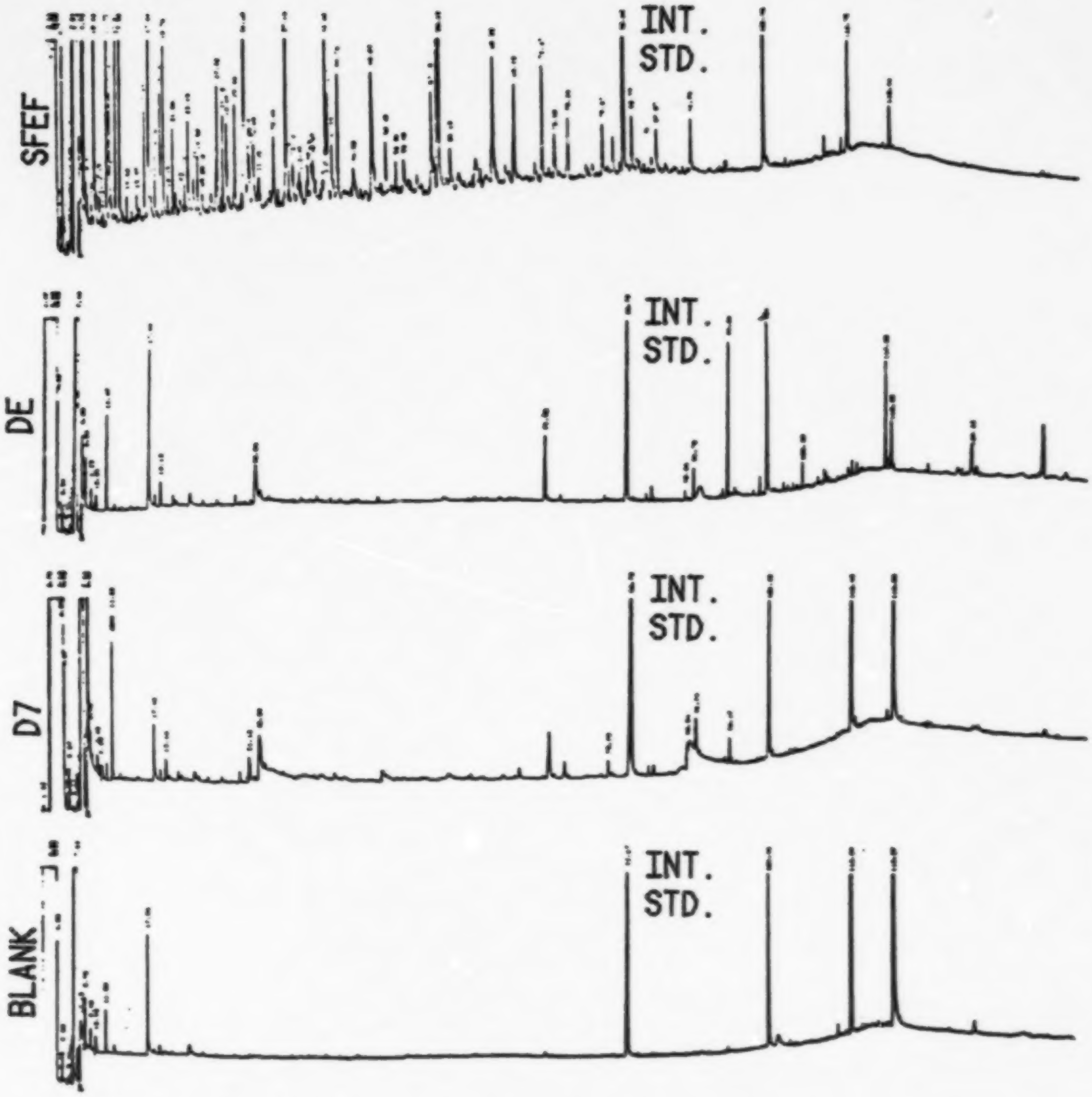


FIGURE 66. Acid extract profiles for Contactor D, Phase 3-0, runday 29.

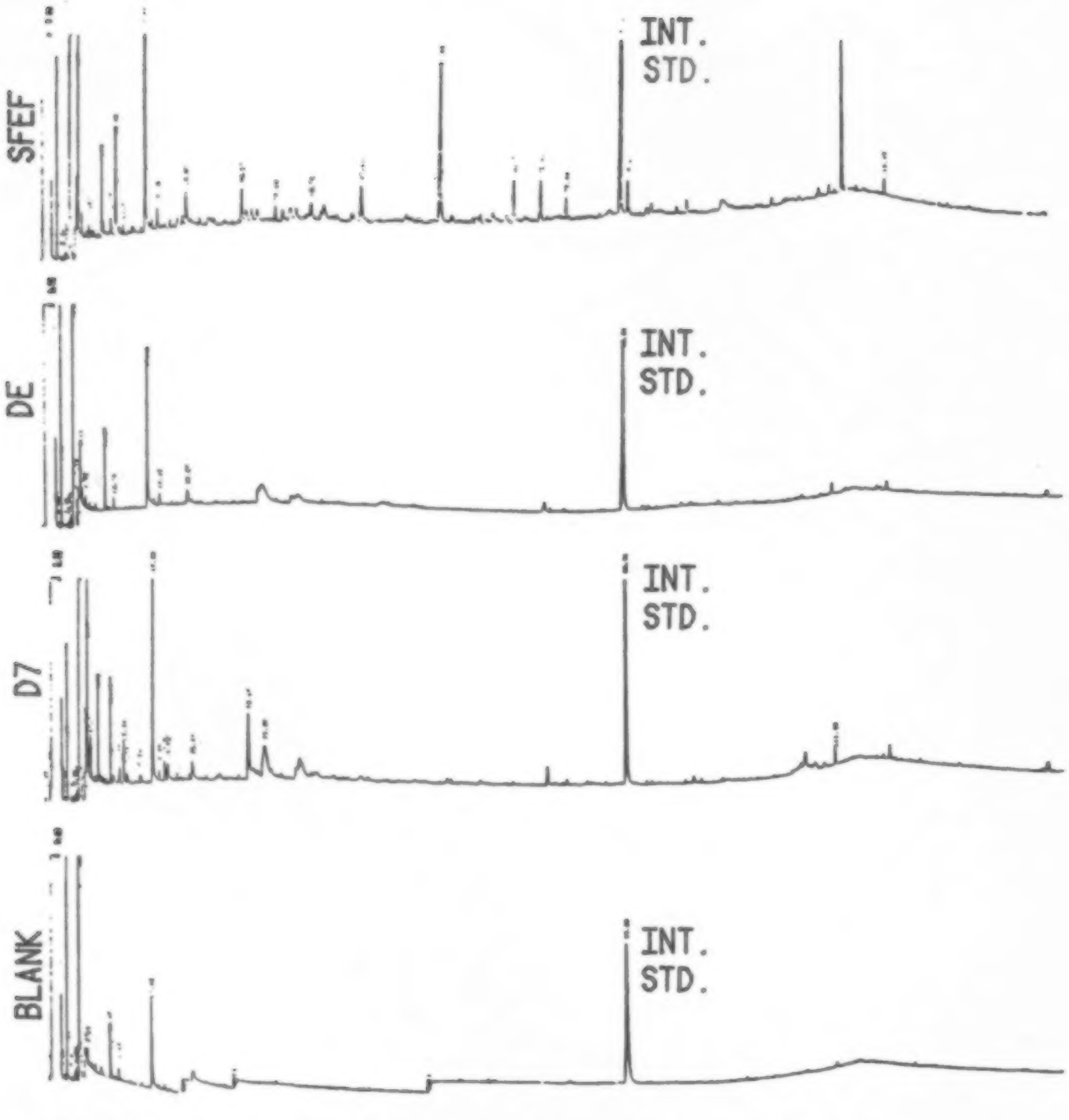


FIGURE 67. Acid extract profiles for Contactor D, Phase 3-0, runday 113.

TABLE 47. ACID EXTRACT COMPOUNDS TENTATIVELY IDENTIFIED BY GC/MS FROM CONTACTOR D

	Percent of Occurrence			
Compound	FLIN[a]	D7[b]	DE[a]	Blank
Dibromochloromethane	70	11	c	c
3,3,3-Trichloro-1-propene	50	22	20	c
1,3,5-Trimethyl-1,3,5-triazine-2,4,6-(1H,2H,3H)-trione	40	c	c	c
7-Oxabicyclo(4.0.1)heptane	30	33	40	10
2-Cyclohexene-1-one	30	22	10	c
Nitrobenzene	30	c	c	c
Tributyl ester phosphoric acid	30	c	c	c
Diethyl ester-1,2-benzenedicarboxylic acid	20	11	20	10
2-Methyl-1,4-dinitrobenzene	20	c	c	c
Tribromomethane	20	c	c	c
Benzoic acid	10	c	c	c
Bromodichloromethane	10	c	c	c
1-Chloro-2-butene	10	c	c	c
Butane	10	c	c	c
Cyclohexene	10	11	c	10
Decycl ester nitric acid	10	c	c	c
1,4-Dichlorobutane	10	11	10	c
1,1-Dichloropropane	10	c	c	c
1,1-Dichloro-2-propanone	10	c	c	c
Dimethyl-1,4-dioxalane	10	c	c	c
2,2-Dimethylpentane	10	c	c	c
Ethylbenzene	10	c	10	c
3-Ethyl-4-methylfurandiene	10	c	c	c
3-Methyl-2-butadiene	10	c	c	10
5-Methylnonane	10	c	c	c
Nitrocyclopentane	10	c	c	c
2-Nitropentane	10	c	c	c
1-Pentyne	10	c	c	c
1-H-Pyrrole	10	11	c	c
1-H-1,2,4-Triazolediamine	10	c	10	c
2,2,3-Trimethylbutane	10	11	c	c
2,2,3-Trimethylpentane	10	c	c	c
Cyclobutanal	c	11	c	c
2-Cyclohexene-1-ol	c	11	c	10
Cyclopropane	c	11	c	c
2,3-Dimethyl-1-butene	c	11	c	c
3,3-Dimethylhexane	c	11	c	c
4-Ethylheptane	c	11	c	c
2-Methylnaphthalene	c	11	10	c
2,4,8-Trimethylnonane	c	11	c	c
1,3-Dimethylbenzene	c	c	10	c
2-Hexene-3-one	c	c	10	c
2,2,5 Trimethylhexane	c	c	10	c
Dibutyl ester ethanoic acid	c	c	c	10
2,2 Proanyl chloride	c	c	c	10

[a] Based on ten samples.
[b] Based on nine samples.
[c] Not detected.

TABLE 48. ESTABLISHED MCLS FOR ORGANIC COMPOUNDS

Compound	MCL (mg/l)
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2,4-D	0.1
2,4,5-TP(Silvex)	0.01
THMs[a]	0.10

[a] Four quarter running average of four sample points.

Discussion of all 225 compounds identified would be a nearly impossible task. Tables 49 and 50 present a data summary of the percent removals by GAC for 55 compounds. These compounds were selected because they were identified most frequently (on 50% of the sample days) and occurred in higher concentrations (greater than 0.00001 mg/l on at least one of those days).

From Tables 49 and 50 it is apparent that, for the most part, GAC removed the identified substances.

However, the degree of removal and the length of effectiveness varies from compound to compound. Some compounds such as tetrachloroethane, 1,2-dichlorobenzene and hexachloroethane were well adsorbed, 85 to 100%, by GAC over the entire sample period. Some compounds were initially well-adsorbed, 85 to 100%, but eventually desorbed with time such as diisopropylether, benzene and carbon tetrachloride. A few compounds were adsorbed only to a limited extent by GAC such as toluene, ethylbenzene, 1,2,4-trimethylbenzene and 1,2,3,4-tetramethylbenzene. Nonanal and decanal were higher in the effluent than in the influent. It is possible that these compounds either leached from the contactor liner, resulted from laboratory contamination or resulted from bacterial degradation of adsorbed organics.

Objective 7. To Compare the Relative Performance of Full-Scale GAC Filters and Contactors after Successive Regenerations

Objective 3 showed that once-regenerated GAC and twice-regenerated GAC were very similar in adsorbent performance to virgin GAC. Laboratory regenerated GAC and parallel pilot column GAC filters were utilized in performing this determination. One objective of Phase 3 was to take this finding one step further and determine if full-scale, on-site regeneration affects the adsorbent performance of GAC in full-scale systems.

The ideal approach to determine the effects of regeneration on the GAC's adsorbent performance would have been to run regenerated systems in parallel with virgin systems as performed in the Phase 2, Objective 3, pilot

TABLE 49. PERCENT REMOVAL DATA SUMMARY OF GROB CLSA RESULTS FOR CONTACTOR A, PHASE 3-0, RUNDAYS 1 THROUGH 134

Compound	Runday				
	1	34	64	113	134
Diisopropylether	a	100	100	100	d
Chloroform	100	98	73	79	70
1,1,1-Trichloroethane	e	95	87	94	98
Benzene	a	100	a	100	99
Carbon tetrachloride	100	94	93	100	100
Cyclohexane	h	21	g	100	c
1,2-Dichloropropane	a	100	g	g	g
Trichloroethene	a	98	98	100	100
Bromodichloromethane	100	100	95	98	90
Methylcyclohexane	d	a	a	100	g
4-Methyl-2-pentanone	a	g	100	100	d
Toluene	38	72	- 3	59	100
Dibromochloromethane	100	100	97	100	100
Hexanal	-100	9	34	e	18
Tetrachloroethene	100	100	98	100	100
Dichloroiodomethane	100	100	100	100	100
Chlorobenzene	a	100	92	100	100
Ethylbenzene	25	c	22	62	99
1,3-and 1,4-Dimethylbenzene	38	51	2	20	98
Bromoform	100	100	100	100	97
Styrene	100	100	40	100	100
1,2-Dimethylbenzene	40	58	17	59	99
Isopropylbenzene	37	50	33	67	99
Propylbenzene	33	36	0	62	98
Ethyl-4-methylbenzene	43	48	17	32	98
1,3,5-Trimethylbenzene	33	c	e	e	e
1,2,4-Trimethylbenzene	27	43	11	46	99
Octanal	b	d	- 77	39	d
1,4-Dichlorobenzene	100	100	100	100	d
1,2,3-Trimethylbenzene	33	46	100	100	99
1,2-Dichlorobenzene	100	100	99.0	100	98
1,3-Diethylbenzene	40	d	e	67	99
1,4-Diethylbenzene	d	-100	h	c	e
5-Ethyl-1,3-dimethylbenzene	60	e	0	57	99
Hexachloroethane	100	99	98	100	99
2-Ethyl-1,4-dimethylbenzene	80	50	d	b	e
4-Ethyl-1,2-dimethylbenzene	50	e	20	50	99
Nonanal	-350	-330	-150	- 9	-1300
3-Ethyl-1,2-dimethylbenzene	70	e	0	b	99
1,2,3,5-Tetramethylbenzene	- 50	55	e	h	99
1,3-Diethyl-5-methylbenzene	50	0	0	100	100
1,2,3,4-Tetramethylbenzene	60	50	50	83	99
Decanal	-150	-680	-120	- 17	d
Dodecanal	a	b	h	100	d
2,6-Bis(1,1-dimethylethyl)2,5-cyclohexadiene-1,4-dione	67	e	70	100	e
Pentadecane	g	a	a	62	b
Diethylphthalate	a	c	h	a	b
2,2,4-Trimethylpenta-1,3-dioldisobutyrate	a	d	c	c	d
2,5-Bis(1,1-dimethylproply)2,5-cyclohexadiene-1,4-dione	b	d	-200	-460	a
1,1,3-Trimethyl-3-phenylindan	33	c	- 10	h	d
Heptadecane	33	d	-180	e	d
Dibutylphthalate	a	c	c	c	h
Dioctylphthalate	a	a	g	100	h
Hexane	a	a	a	a	a
Methylcyclopentane	a	a	a	a	a

[a] Not detected.
[b] Not detected in influent.
[c] Not quantified.
[d] Influent not quantified.
[e] Effluent not quantified.
[f] Not scanned.
[g] Influent not quantified and effluent not detected.
[h] Influent not detected and effluent not quantified.

TABLE 50. PERCENT REMOVAL DATA SUMMARY OF GROB CLSA RESULTS FOR CONTACTOR A, PHASE 3-0, RUNDAYS 162 THROUGH 302

Compound	Runday					
	162	190	218	246	274	302
Diisopropylether	67	-114	f	g	b	g
Chloroform	-340	- 55	f	75	- 8	-1200
1,1,1-Trichloroethane	56	70	f	c	- 35	d
Benzene	100	100	a	40	- 4	- 46
Carbon tetrachloride	100	a	100	e	e	- 96
Cyclohexane	90	- 46	d	c	c	c
1,2-Dichloropropane	a	100	a	a	h	h
Trichloroethene	100	100	a	100	a	17
Bromodichloromethane	0	14	- 87	35	29	-580
Methylcyclohexane	100	d	g	c	g	g
4-Methyl-2-pentanone	88	-166	b	a	g	a
Toluene	90	- 83	42	15	- 21	- 75
Dibromochloromethane	68	71	62	-714	73	- 93
Hexanal	63	- 15	e	a	0	g
Tetrachloroethene	100	100	100	e	86	92
Dichloroiodomethane	100	24	100	a	100	100
Chlorobenzene	100	a	a	h	c	g
Ethylbenzene	e	-286	e	c	-3900	65
1,3-and 1,4-Dimethylbenzene	71	-220	33	a	a	a
Bromoform	75	83	90	c	100	50
Styrene	95	h	a	a	e	e
1,2-Dimethylbenzene	84	- 75	e	e	-2000	23
Isopropylbenzene	96	0	b	g	d	c
Propylbenzene	83	- 33	a	g	c	c
Ethyl-4-methylbenzene	e	- 25	56	100	- 43	-350
1,3,5-Trimethylbenzene	c	d	c	e	e	16
1,2,4-Trimethylbenzene	68	0	36	57	-100	- 24
Octanal	68	- 60	e	h	44	d
1,4-Dichlorobenzene	99	100	100	e	89	86
1,2,3-Trimethylbenzene	80	0	d	e	e	- 12
1,2-Dichlorobenzene	99	98	100	100	100	100
1,3-Diethylbenzene	g	h	c	g	c	c
1,4-Diethylbenzene	83	h	c	g	g	c
5-Ethyl-1,3-dimethylbenzene	e	0	d	100	e	e
Hexachloroethane	99	100	100	a	100	100
2-Ethyl-1,4-dimethylbenzene	c	g	d	e	c	e
4-Ethyl-1,2-dimethylbenzene	73	0	a	100	e	-220
Nonanal	54	- 80	- 23	- 48	23	- 15
3-Ethyl-1,2-dimethylbenzene	b	b	b	g	c	g
1,2,3,5-Tetramethylbenzene	e	0	d	e	e	0
1,3-Diethyl-5-methylbenzene	a	a	a	a	g	g
1,2,3,4-Tetramethylbenzene	87	e	b	g	e	e
Decanal	65	- 76	9	- 22	19	- 10
Dodecanal	68	- 4	- 5	h	6	100
2,6-Bis(1,1-dimethylethyl)2,5-cyclohexadiene-1,4-dione	94	100	100	c	100	- 52
Pentadecane	h	b	- 45	- 44	42	75
Diethylphthalate	29	48	g	42	e	35
2,2,4-Trimethylpenta-1,3-dioldisobutyrate	65	100	a	a	91	- 2
2,5-Bis(1,1-dimethylproply)2,5-cyclohexadiene-1,4-dione	76	a	c	- 81	c	83
1,1,3-Trimethyl-3-phenylindan	e	61	-120	21	84	g
Heptadecane	26	12	- 73	57	21	14
Dibutylphthalate	c	c	a	h	80.0	c
Dioctylphthalate	h	a	a	a	a	a
Hexane	a	- 54	f	a	- 12	100
Methylcyclopentane	g	- 6	f	e	41	c

[a] Not detected.
[b] Not detected in influent.
[c] Not quantified.
[d] Influent not quantified.
[e] Effluent not quantified.
[f] Not scanned.
[g] Influent not quantified and effluent not detected.
[h] Influent not detected and effluent not quantified.

column work. This approach would eliminate the problem of varying influent concentrations when two systems were brought on line at different times. However, another more important objective of Phase 3 was to determine the GAC losses across the regeneration system. Construction delays for the regeneration system and for the contactors severely reduced the amount of time available for GAC loss determination. In order to generate sufficient data to determine the GAC loss across the regeneration system it was necessary to obtain maximum utilization of the regeneration system. This involved bringing all the GAC systems on line as soon as possible. It also forced the regeneration of several GAC systems before they had reached complete exhaustion as defined by the exhaustion criteria discussed in Objective 9. Thus, it was not possible to compare the adsorbent performance of virgin and regenerated GAC using parallel runs.

The above considerations made it difficult to compare the adsorptive capacity of virgin and regenerated GAC. Since it was not possible to perform parallel runs, the two systems received influent waters with varying concentrations. The systems also were started at different times of the year which introduced temperature variations. It was hoped that these differences would not be significant and that percent removal curves could be used to compare the virgin and regenerated GAC.

Figures 68 and 69 present percent removal graphs for TOC and THMSIMDIST from Contactor D, Phase 3-0, 3-1 and 3-2, respectively. Figures 70 and 71 present percent removal graphs for TOC and INST $CHCl_3$ from GAC Filter 15A, Phase 3-0, 3-1, 3-2 and 3-3, respectively. The wide variation in the influent concentration between phases for both systems is presented in Table 51. From the figures, it is apparent that varying influent concentrations resulted in varying percent removal graphs. This is especially true in the INST $CHCl_3$ percent removal graph for GAC Filter 15A (Figure 71). Contactor D (Figure 69) gives a good graphic presentation of the effects that three different THMSIMDIST average influent concentrations, (59.0 µg/l, 87.4 µg/l and 124 µg/l) have on the percent removal curves. Initially, while the GAC had many adsorptive sites there was very little difference between the curves. As the run progressed, fewer adsorptive sites were available for the GAC systems that received the larger influent concentration in Phases 3-0 and 3-1, causing them to adsorb a smaller percentage of the influent concentration.

It appeared that in order to determine if regeneration had any effect on the GAC's adsorbent performance, two systems with similar influent concentrations must be compared. In Figure 68, the average TOC influent concentration for virgin GAC, Phase 3-0, and twice-regenerated GAC, Phase 3-2, were very similar. In Figure 70, the average TOC influent concentration for virgin GAC, Phase 3-0, and GAC regenerated three times, Phase 3-3, were very similar. If the GAC adsorbent performance was reduced due to regeneration, the curves for the regenerated systems would be below those for the virgin GAC. This is not evident in the figures. From this discussion, it is apparent that only percent removal curves from systems with similar influent concentrations can be used to study the effect of regeneration on the

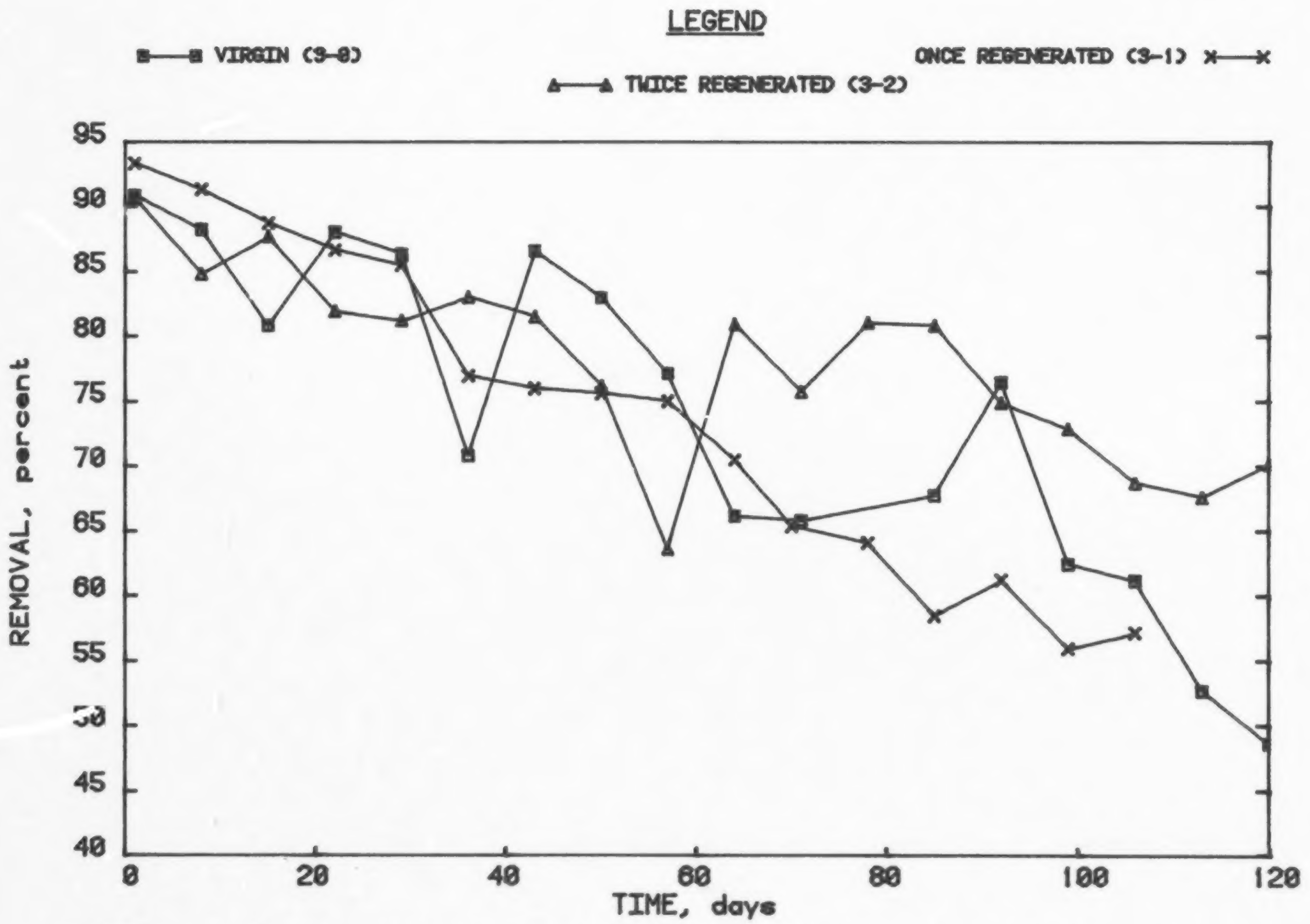


FIGURE 68. Total organic carbon (TOC) percent removal curves for multiple runs of Contactor D effluent, Phase 3.

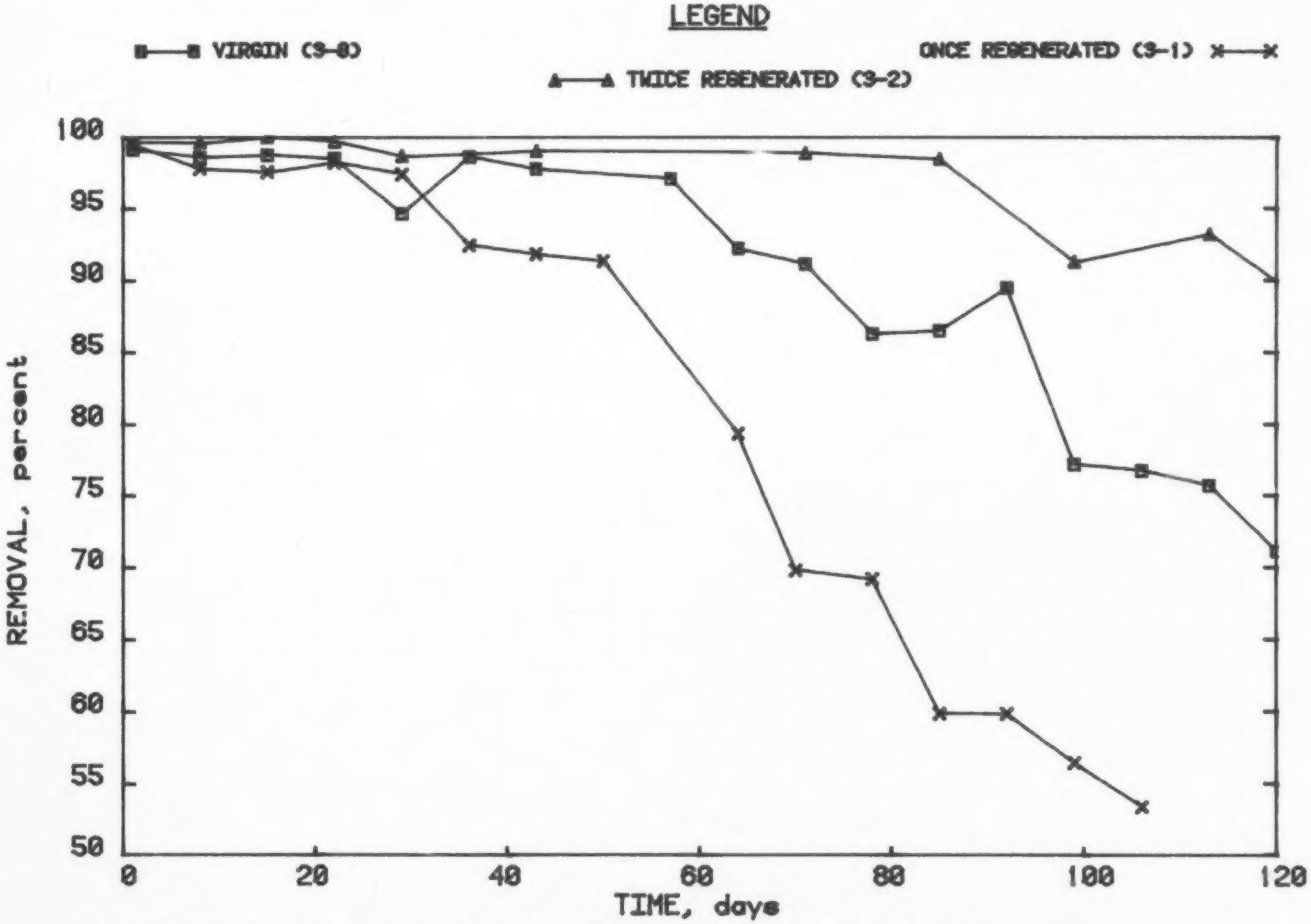


FIGURE 69. Three-day simulated distribution system THM (STT3) percent removal curves for multiple runs of Contactor D effluent, Phase 3.

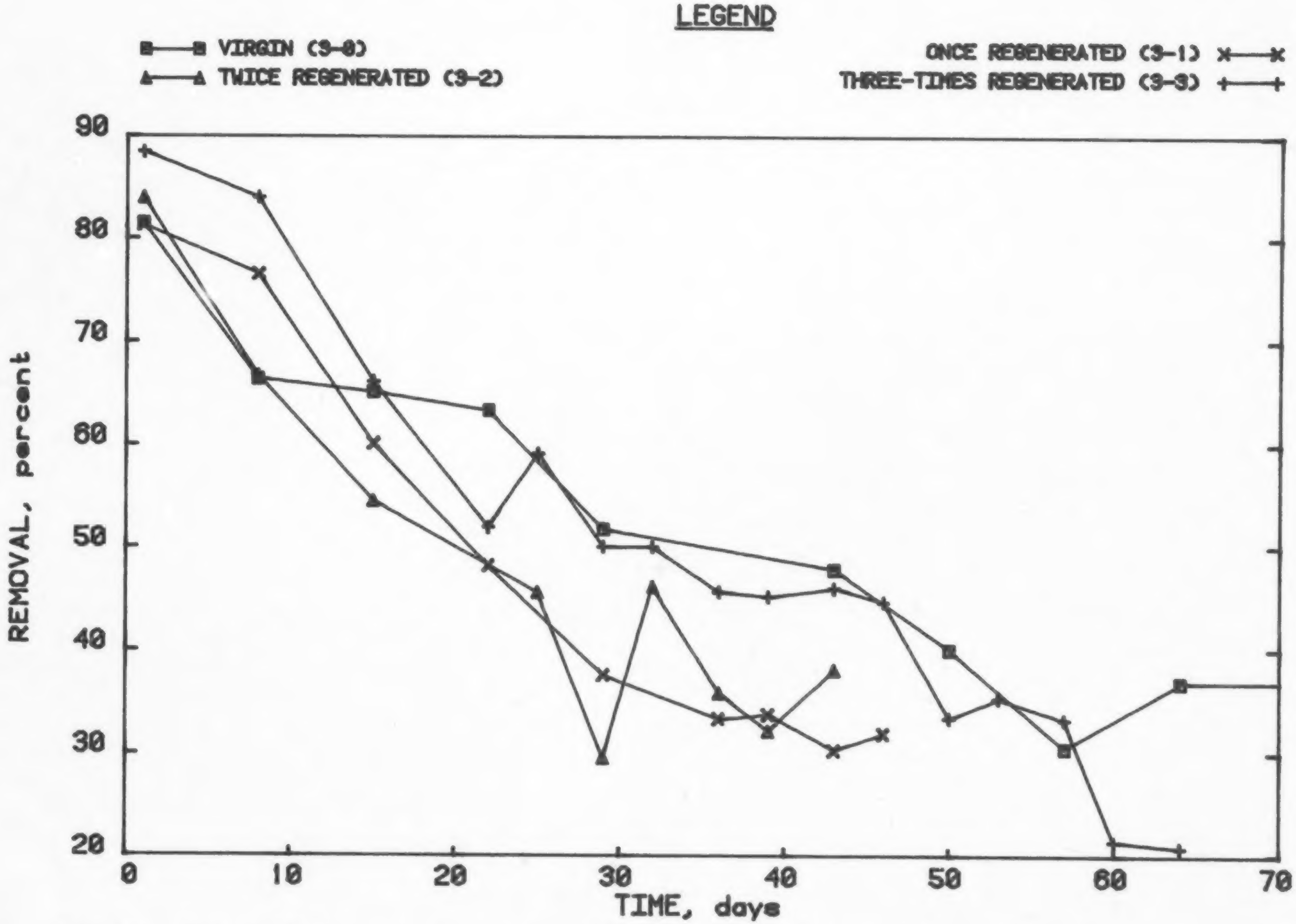


FIGURE 70. Total organic carbon (TOC) percent removal curves for multiple runs of GAC Filter 15A effluent, Phase 3.

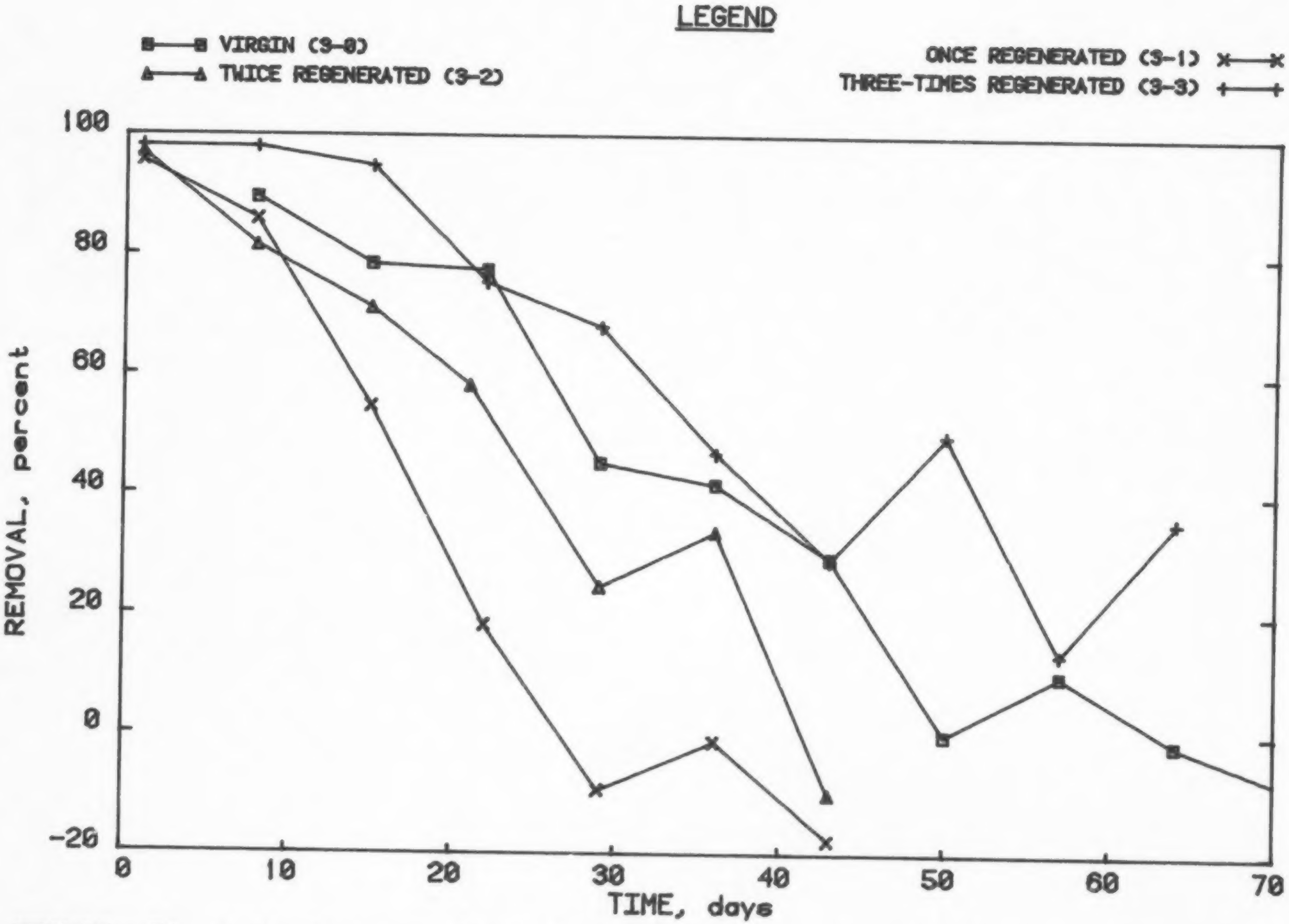


FIGURE 71. Instantaneous chloroform (ICLR) percent removal curves for multiple runs of GAC Filter 15A effluent, Phase 3.

TABLE 51. AVERAGE INFLUENT CONCENTRATION FOR CONTACTOR D AND GAC FILTER 15A

	Contactor D Influent			GAC Filter 15A Influent			
Parameter	Phase 3-0	Phase 3-1	Phase 3-2	Phase 3-0	Phase 3-1	Phase 3-2	Phase 3-3
TOC	1914	2627	1818	1870	3275	2330	1988
THMFP	184	222	149	216	290	217	184
THMSIMDIST	87.4	124	59.0	74.3	179	95.5	57.6
Chloroform	25.0	31.4	11.8	14.3	54.6	17.0	8.9
Bromodichloromethane	8.7	18.0	8.9	4.8	19.7	16.4	6.7

adsorbent performance. For systems with similar influent concentrations, it appears that reactivation had restored the GAC to its virgin adsorptive capacity.

In order to further determine the effect of regeneration on the adsorbent performance, it was necessary to first normalize the varying influent concentration. One way of eliminating the varying influent concentration was by using the cumulative summation concentration of the various parameters applied per weight of GAC rather than the actual influent concentration. These data were further normalized by using the weight of parameter adsorbed per weight of GAC. This eliminated the variations in GAC weight from system to system. The cumulative summation concentration per weight of GAC was plotted against the cumulative amount adsorbed per weight of GAC. Therefore, a GAC System which was 100% effective in the removal of organics would result in a 45° slope.

Figures 72 through 74 illustrate this effect for INST CHCl$_3$, INST CHBrCl$_2$ and TOC, respectively, from Contactor D for Phases 3-0, 3-1 and 3-2. Adsorption of specific compounds and groups of compounds, were not significantly affected by multiple regenerations. Normalization techniques enabled the comparison of different runs.

Figures 75 through 77 present the same effects for INST CHCl$_3$, TOC and THMFP, respectively, from GAC Filter 15A for Phases 3-0, 3-1, 3-2 and 3-3. Figures 76 and 77 represent groups of compounds which show a pattern similar to that observed in the contactors except for the TOC curves. The TOC curves separated as more substance passed through the GAC filter. The INST CHCl$_3$ curves in Figure 75 are only identical up to a point, after which they separate quite dramatically. Again Figure 75, Phase 3-0, desorption is observed when the influent concentration decreases, with adsorption occuring when the influent concentration increases. As expected, the effects of varying influent concentration on equilibrium were minimized by the normalization techniques, but not completely eliminated.

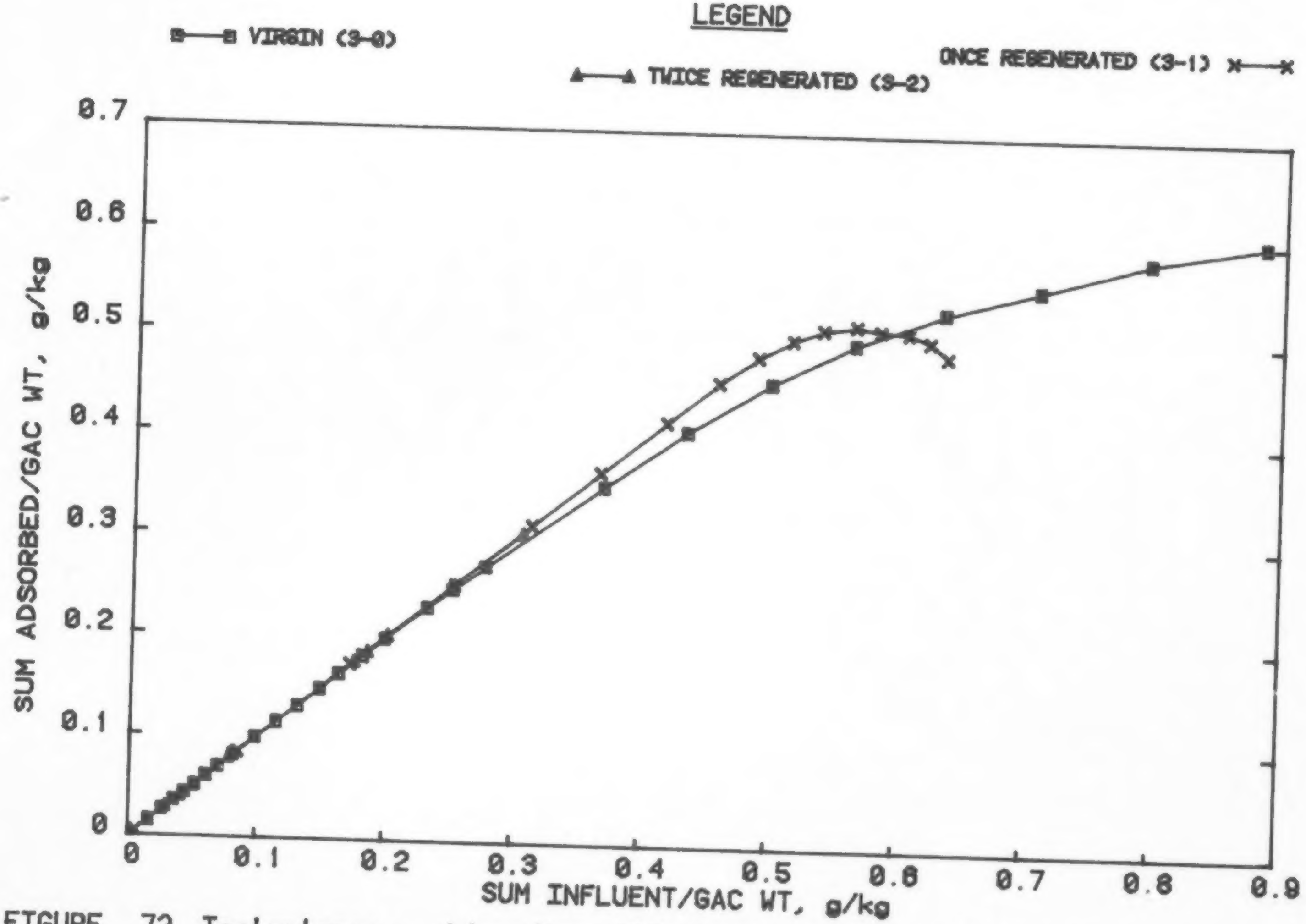


FIGURE 72. Instantaneous chloroform (ICLR) adsorbed per GAC weight for multiple runs of Contactor D effluent, Phase 3.

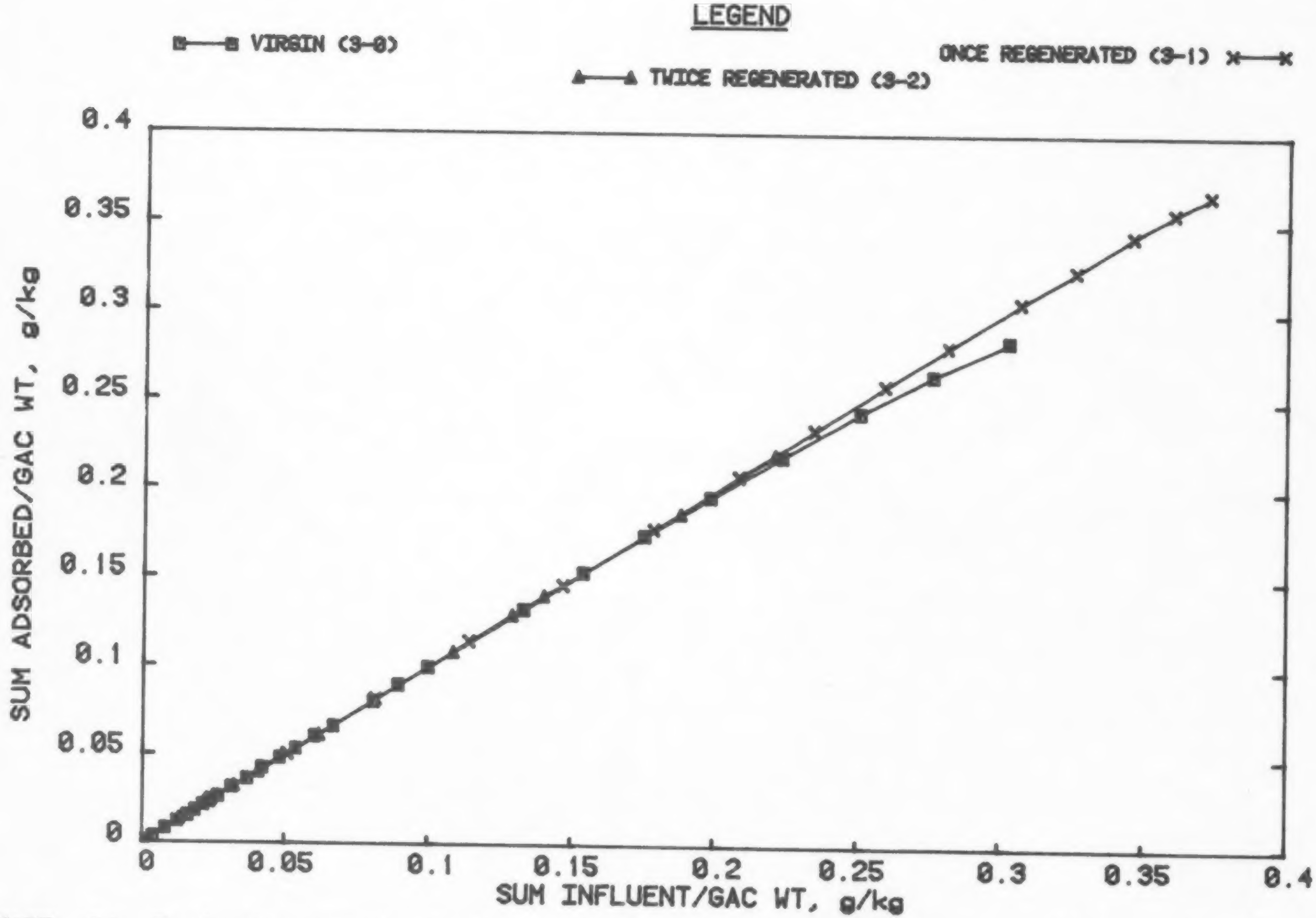


FIGURE 73. Instantaneous bromodichloromethane (ICL2) adsorbed per GAC weight for multiple runs of Contactor D effluent, Phase 3.

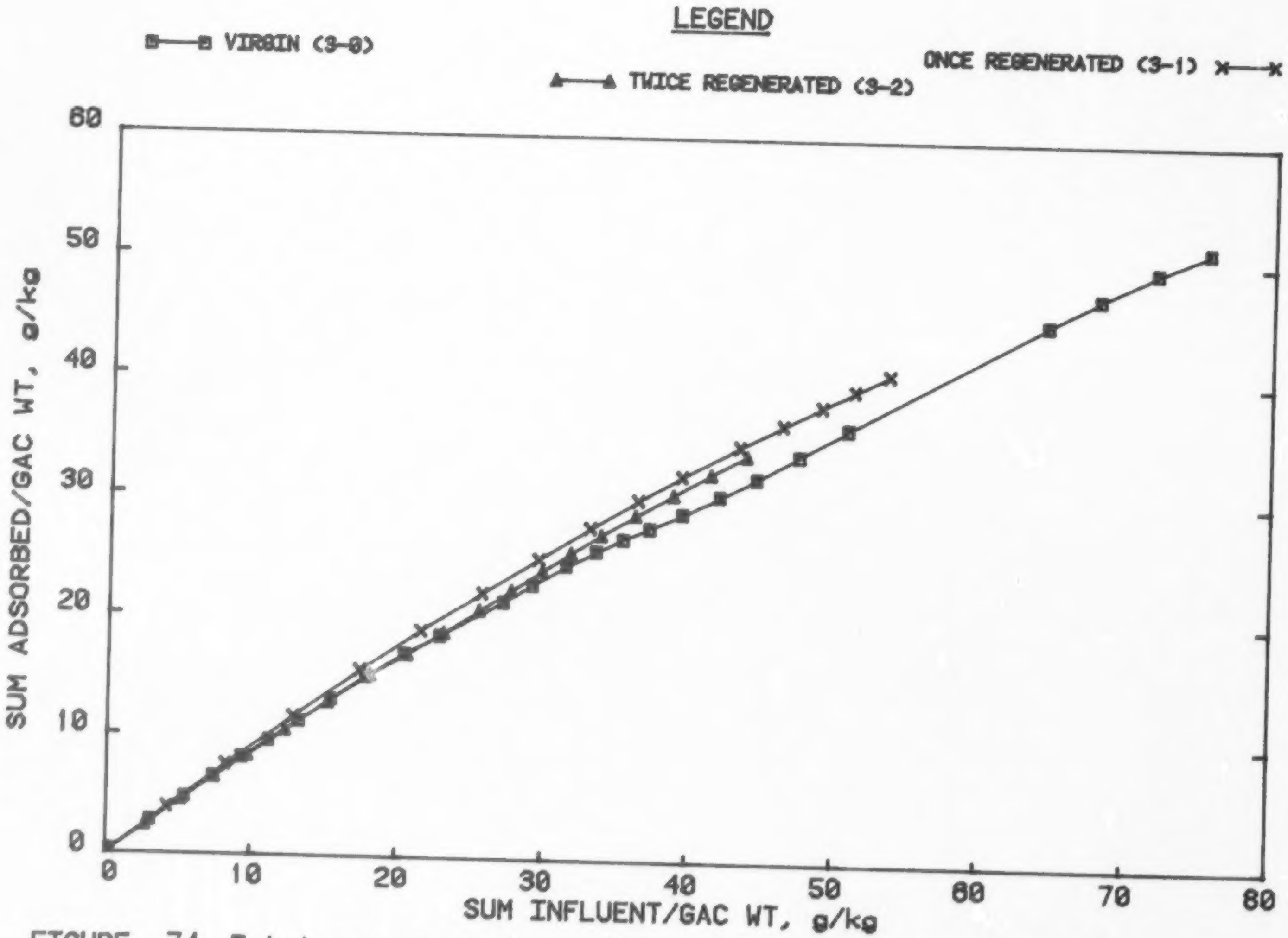


FIGURE 74. Total organic carbon (TOC) adsorbed per GAC weight for multiple runs of Contactor D effluent, Phase 3.

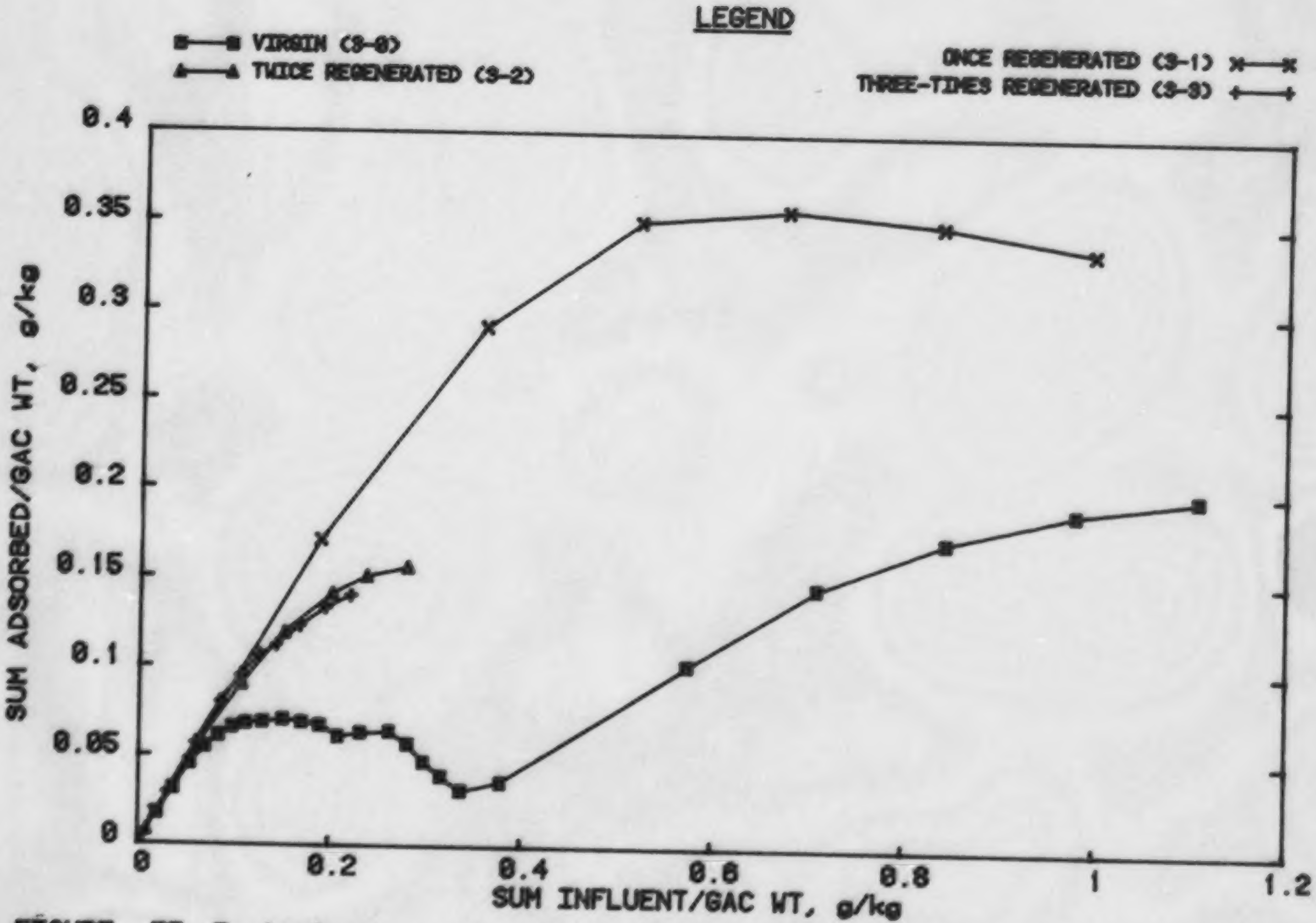


FIGURE 75. Instantaneous chloroform (ICLR) adsorbed per GAC weight for multiple runs of GAC Filter 15A effluent, Phase 3.

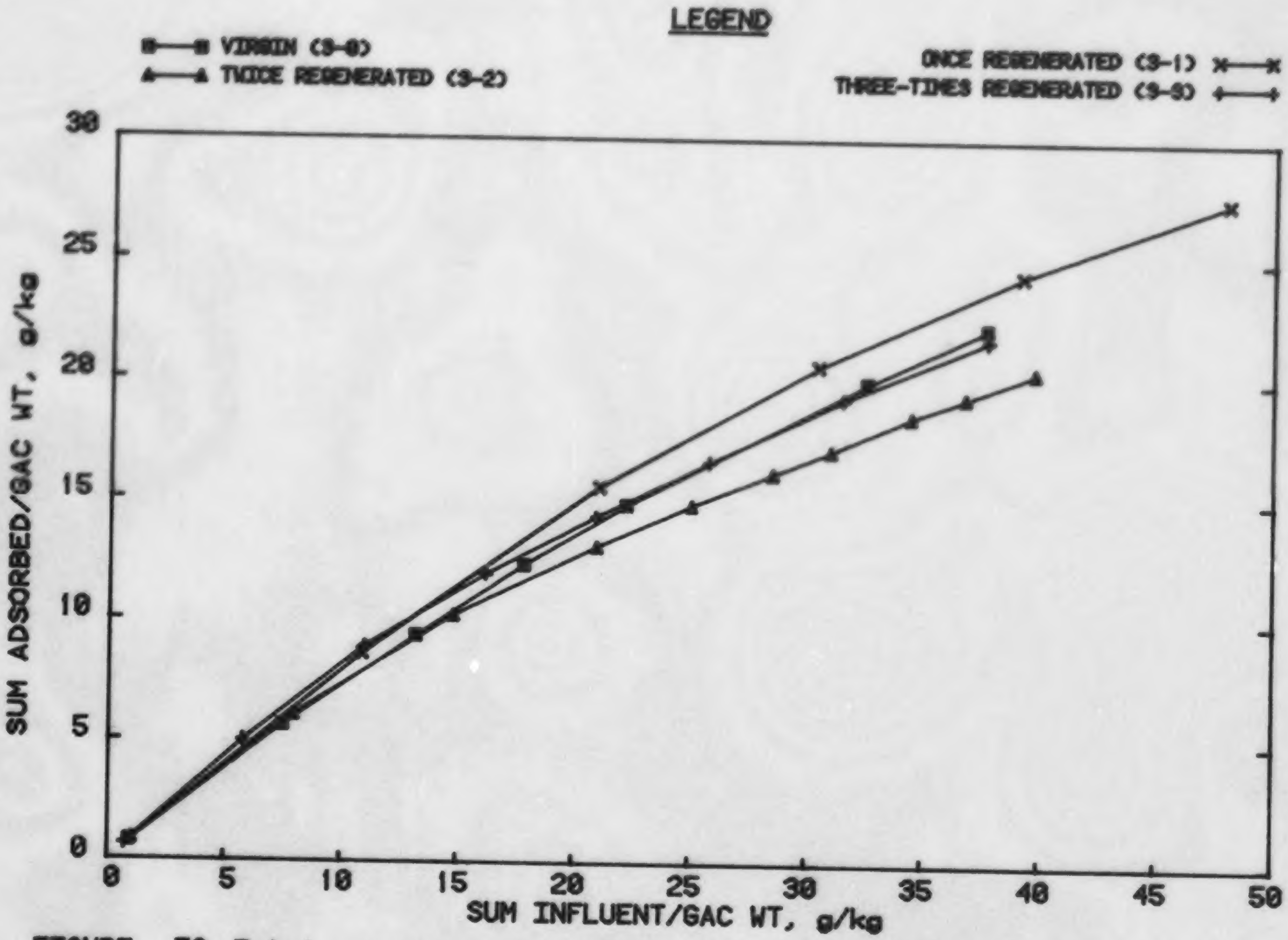


FIGURE 76. Total organic carbon (TOC) adsorbed per GAC weight for multiple runs of GAC Filter 15A effluent, Phase 3.

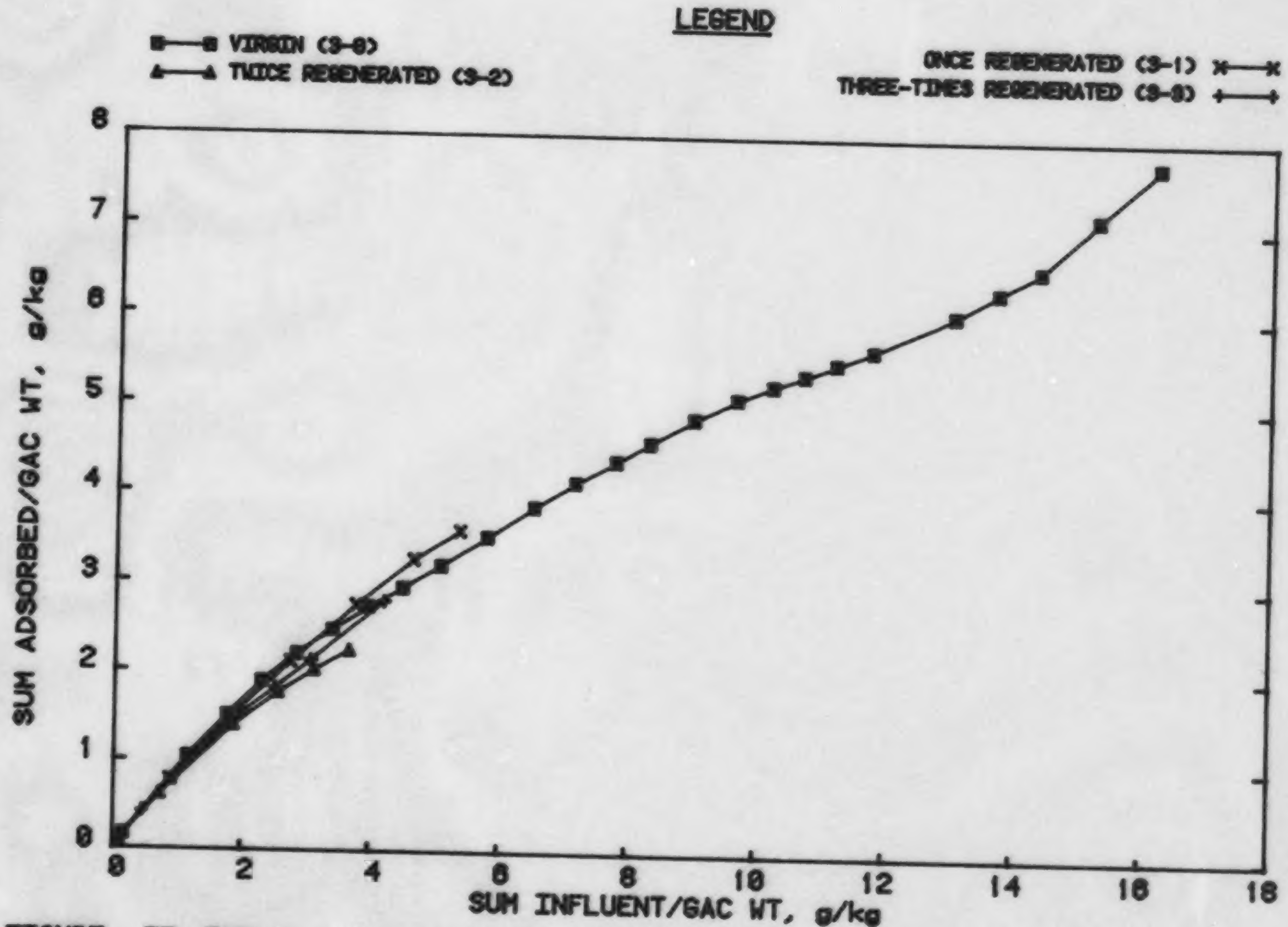


FIGURE 77. THM formation potential (FTTT) adsorbed per GAC weight for multiple runs of GAC Filter 15A effluent, Phase 3.

Graphs of the cumulative summation concentraion per weight of GAC of the various parameters applied against the cumulative amount adsorbed per weight of GAC was the best method available for comparing the adsorbent performance of virgin and regenerated GAC. Full-Scale, on-site regeneration restores the GAC to its virgin adsorptive capacity. This is further supported by conclusions found in Objective 10 which used iodine number, molasses number, BET surface area determination and modified phenol value to compare the effects of regeneration on adsorptive capacity.

Objective 8. Correlation Between Pilot and Full-Scale GAC Systems.

The primary purpose of this objective was to determine the ability of pilot systems to predict full-scale performance. Percent removal graphs were studied in this evaluation for the following parameters: INSTTHM, THMSIMDIST, TOC, CAOX, and acid extract GC/FID profiles. Although other parameters were considered, they were not significant for this evaluation. Data concerning these parameters can be found in Volumes 2 and 3.

The evaluations conducted under this objective utilized three criteria for comparing the pilot and full-scale systems: EBCT, percent removal and exhaustion (the preferred criteria stated in Objective 9).

GAC Filters--

Data discussed below are contained in Table 52. During Phase 3-0, the EBCTs were equal for both the pilot and full-scale GAC filters based on throughput for the length of the run. Figures 78 and 79 and show the percent removal of the two systems for THMSIMDIST and TOC to be identical.

TABEL 52. COMPARISON OF PILOT AND FULL-SCALE GAC FILTER SYSTEMS

GAC Filter System	Phase Run	Hydraulic Loading Rate lpm/sq m	Hydraulic Loading Rate gpm/sq ft	Exhaustion TOC (runday)	Exhaustion THMSIMDIST (runday)
Pilot	3-0	102	2.5	57	176
Fullscale		102	2.5	57	176
Pilot	3-1	97	2.4	22	36
Fullscale		102	2.5	22	36
Pilot	3-2	94	2.3	29	a
Fullscale		102	2.5	21	a
Pilot	3-3	94	2.3	50	a
Fullscale		102	2.5	46	a

[a] Exhaustion did not occur during life of this run.

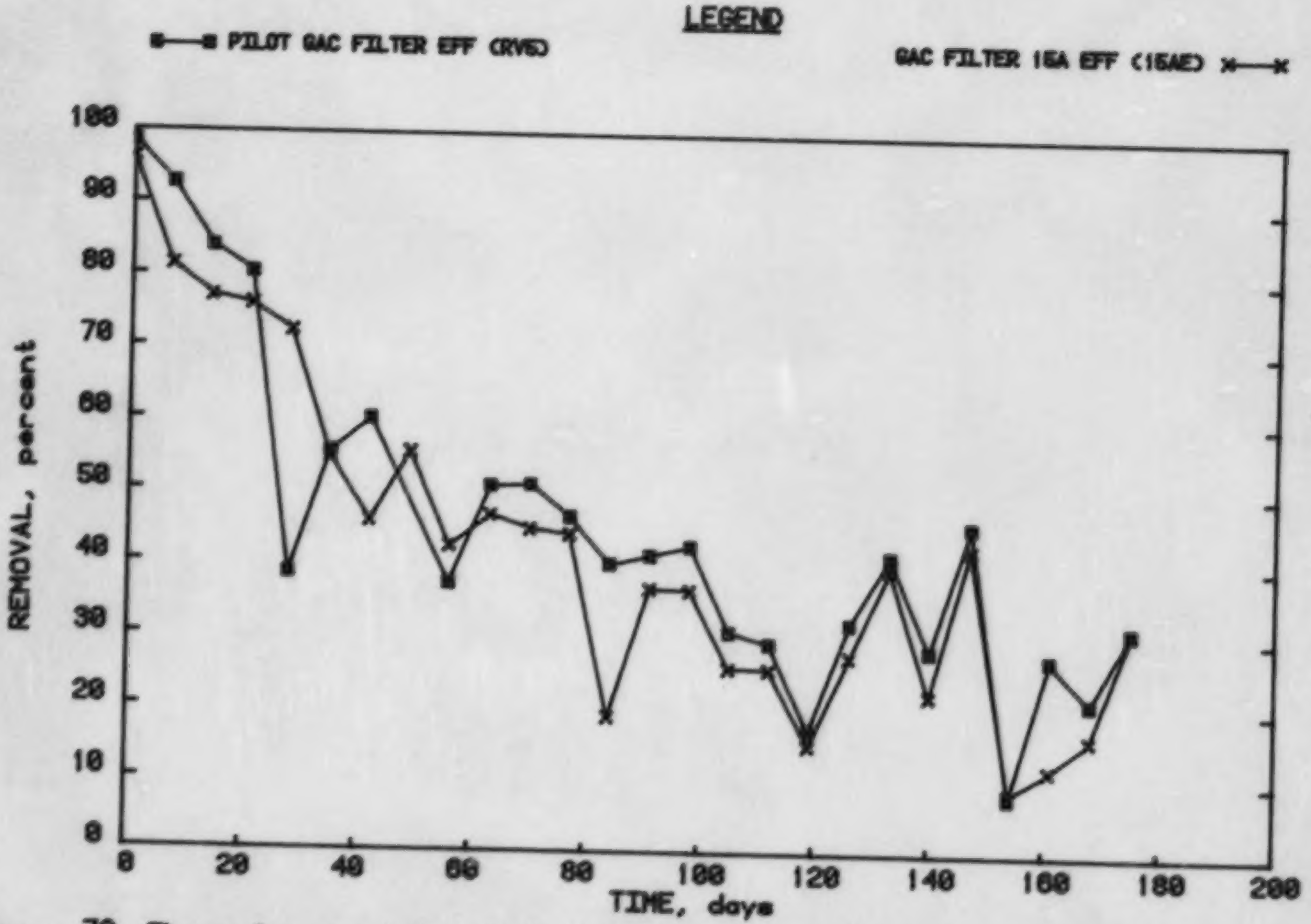


Figure 78. Three-day simulated distribution system THM (STT3) percent removal curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-0.

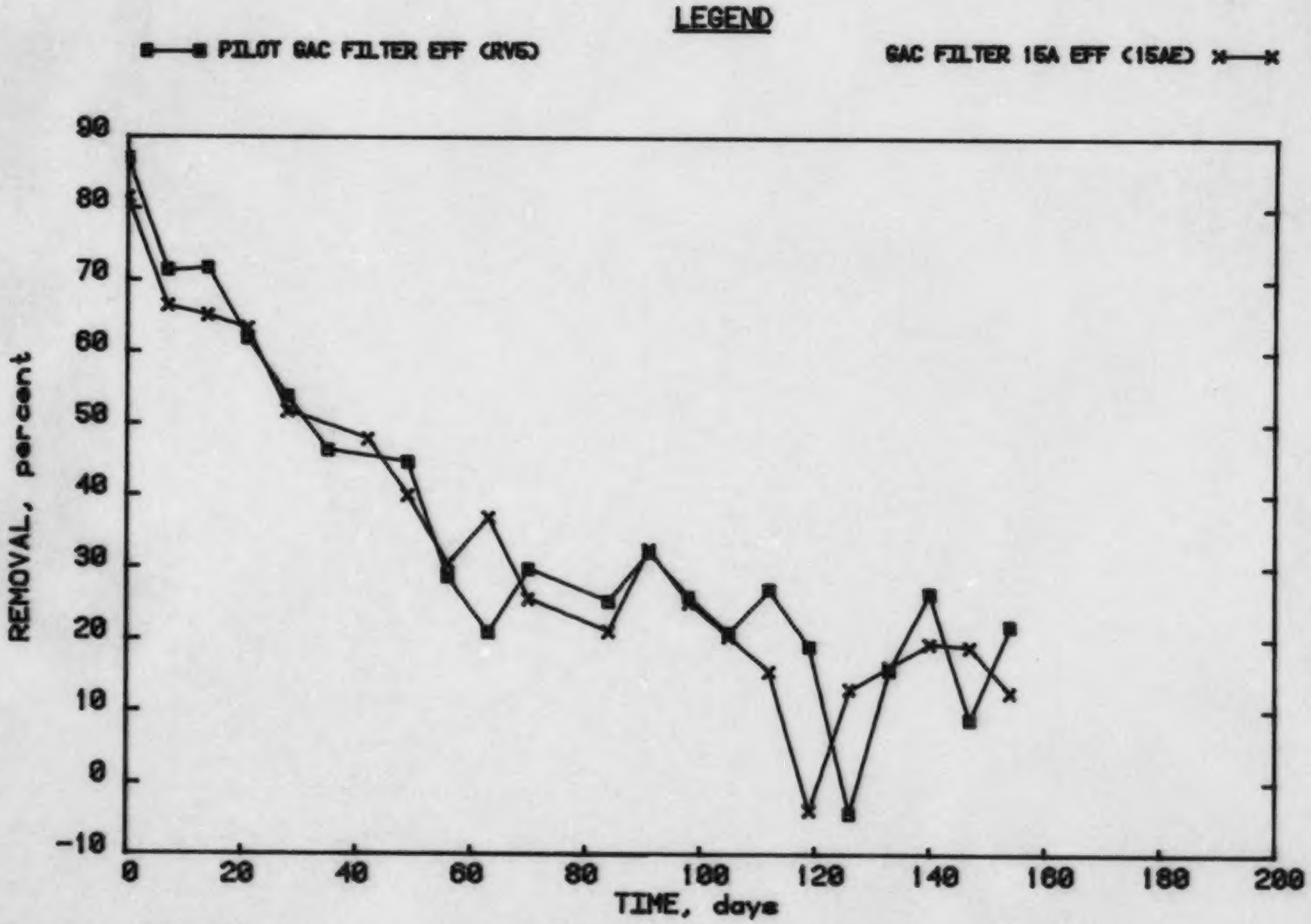


Figure 79. Total organic carbon (TOC) percent removal curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-0.

Breakthrough curves (Figures 80 and 81) for the same parameters, when evaluated for exhaustion criteria, verified these results.

Throughput calculations for Phase 3-1 showed the EBCTs to be the same. Figure 82 demonstrates that the pilot column was about 5% more efficient than the GAC filter for THMSIMDIST removal. Figure 83 shows about a 5% better TOC removal for the pilot GAC filter for 25 days but both systems were equal thereafter. Exhaustion for TOC and THMSIMDIST on the same runday (Figures 84 and 85).

Throughput calculations for Phase 3-2 showed a 10% lesser volume of water passed through the pilot system causing a longer EBCT. This effect is reflected in Figure 86 where the pilot column is removing 20% to 30% more THMSIMDIST. This was further evidenced for TOC in Figure 87, but only by about 10%. THMSIMDIST exhaustion did not occur during the run (Figure 88), however, the exhaustion criterion was met for TOC on runday 29 for the pilot system and on runday 21 for the GAC filter (Figure 89). This represented up to a 30% greater efficiency in the pilot system.

In Phase 3-3, the EBCT was 5% longer for the pilot column which explains the approximate 5% greater removal of THMSIMDIST (Figure 90). TOC percent removal curves were identical (Figure 91). THMSIMDIST exhaustion did not occur (Figure 92). The exhaustion criterion for TOC was reached in 50 days in the pilot system and in 46 days in the GAC filter, indicating up to a 9% greater efficiency in the pilot system (Figure 93).

A review of the acid extract GC/FID profiles, comparing the two systems, indicated that the organics removal efficiency was essentially identical as shown in the Figure 94.

Data available for CAOX showed essentially no difference in removals for the two systems (Figure 95).

Contactors--

Data discussed below are contained in Table 53.

Phase 3-0 EBCTs were practically the same for the two systems. Figures 96 and 97 showed a 5% greater efficiency of the contactor over the pilot system based on THMSIMDIST and TOC. Exhaustion criteria verify this 5% better removal (Figures 98 and 99).

The EBCTs observed during Phase 3-1 resulted in a 4% longer contact time in the pilot system. However, this advantage for the pilot system was not apparent in THMSIMDIST and TOC removal graphs (Figures 100 and 101). These data showed a 10% better efficiency for the contactor system. Exhaustion did not occur during this run as shown in Figures 102 and 103.

An 8% longer EBCT was experienced for the pilot system during Phase 3-2. Although this longer EBCT should have improved the efficiency of the pilot system, this was not evidenced in the percent removal graphs

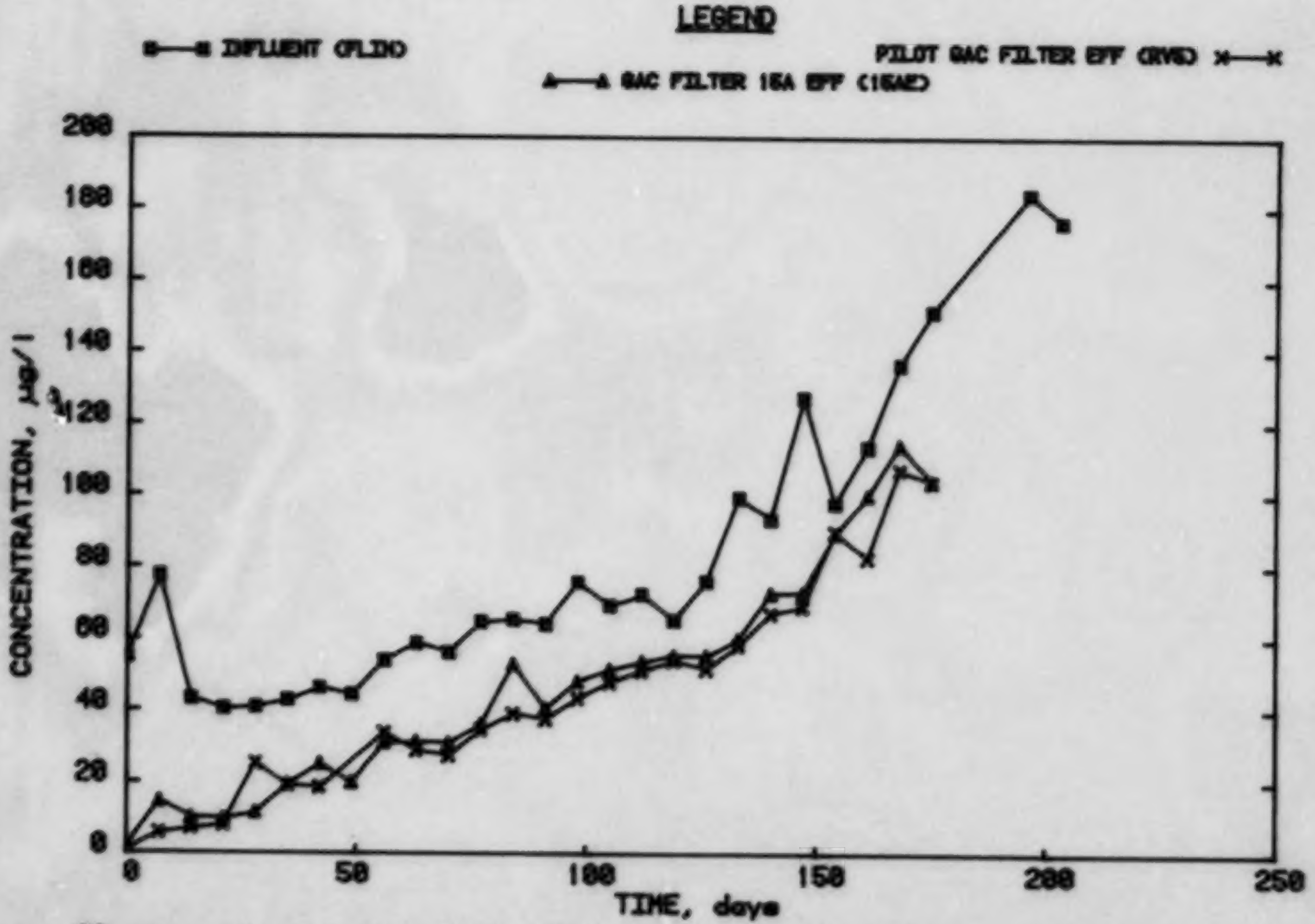


Figure 80. Three-day simulated distribution system THM (STT3) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-0.

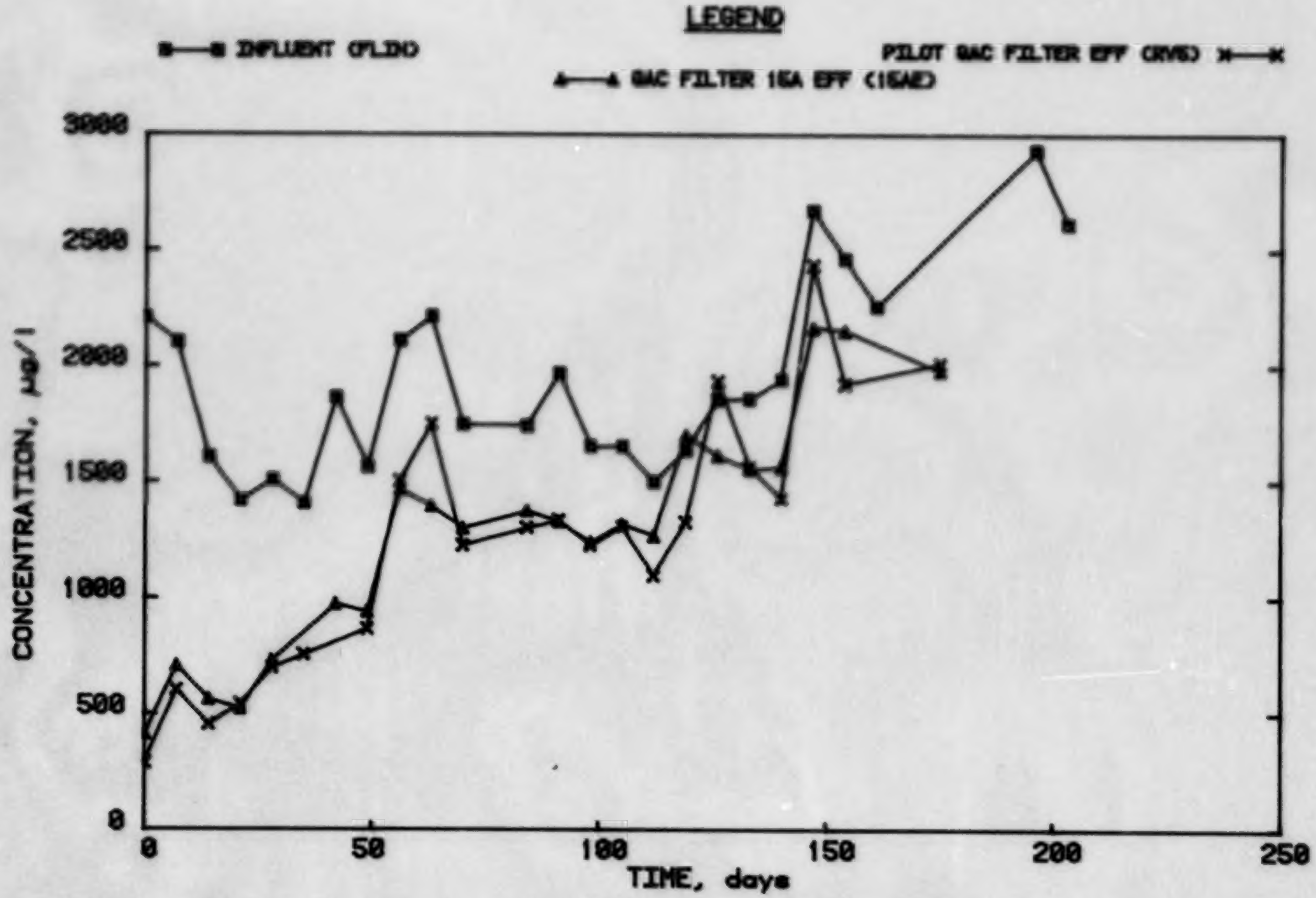


Figure 81. Total organic carbon (TOC) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-0.

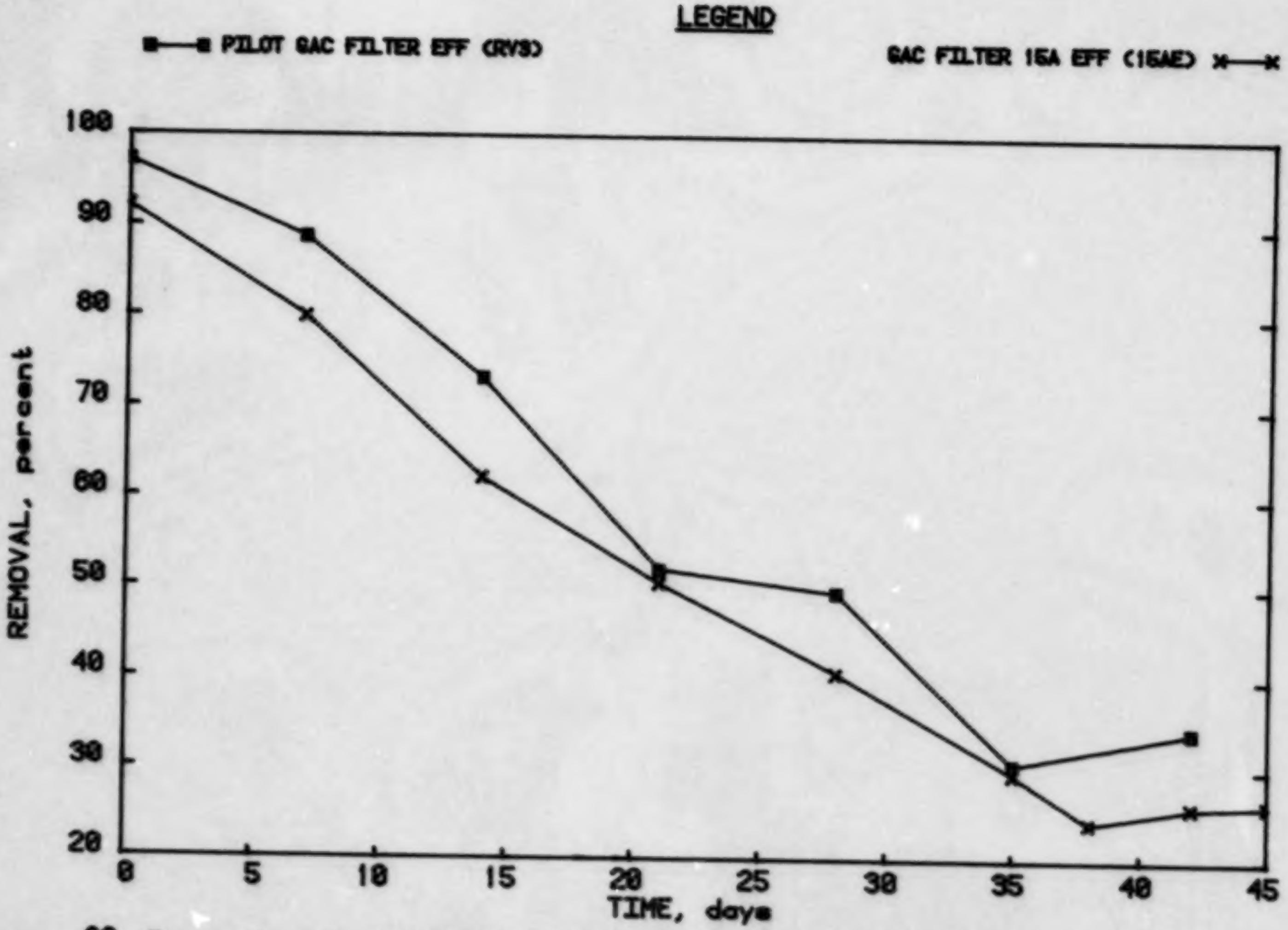


Figure 82. Three-day simulated distribution system THM (STT3) percent removal curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-1.

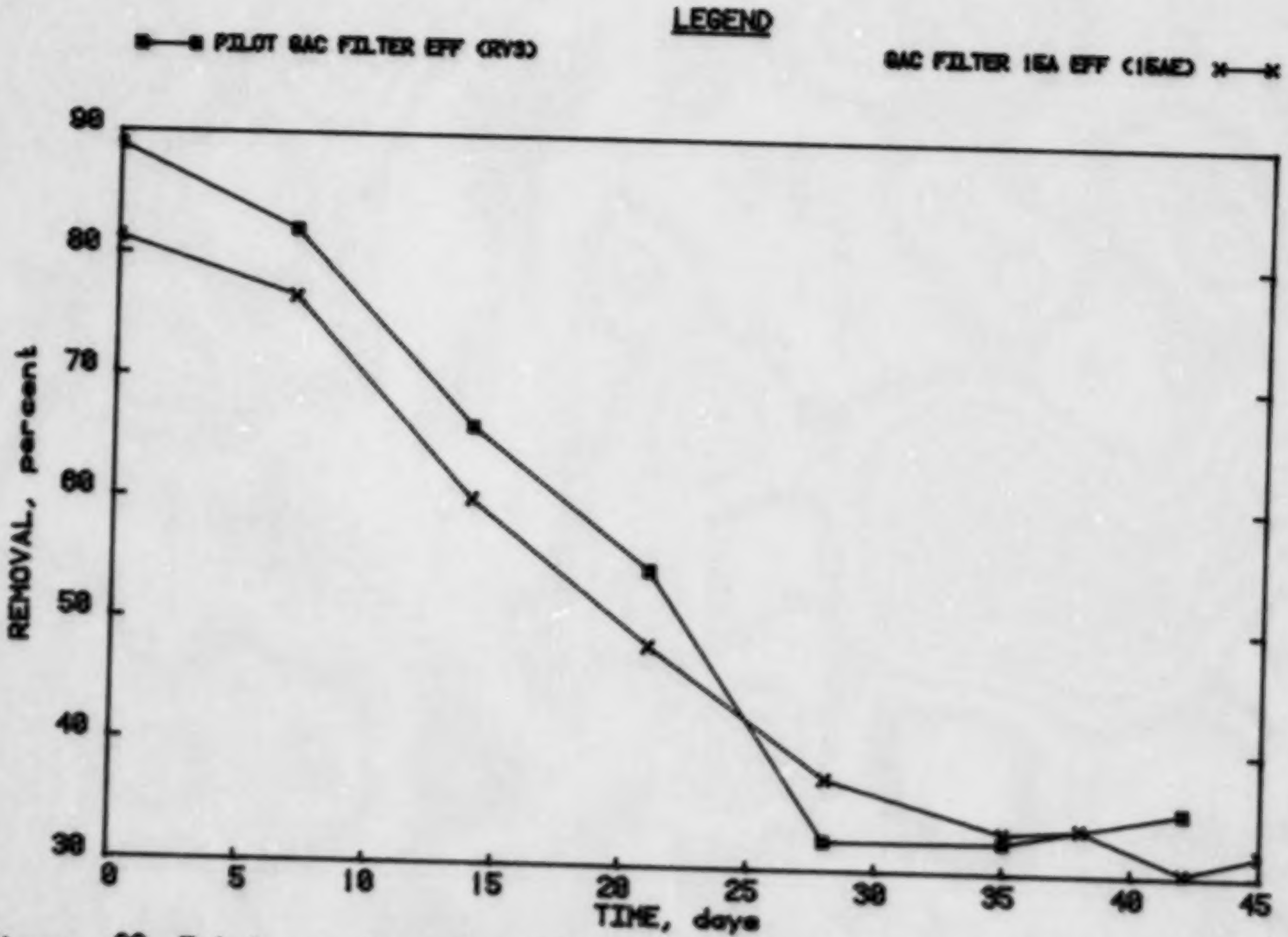


Figure 83. Total organic carbon (TOC) percent removal curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-1.

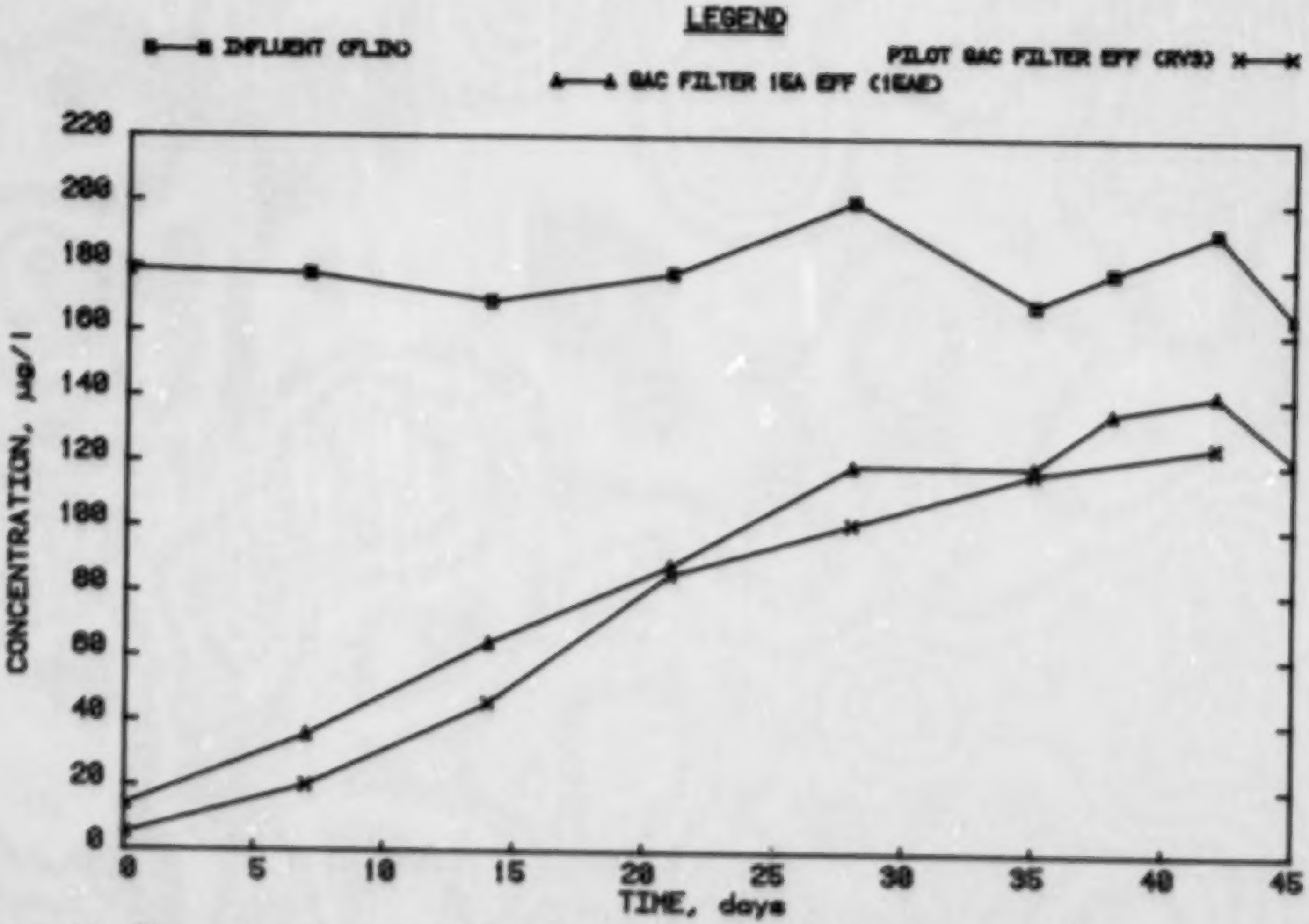


Figure 84. Three-day simulated distribution system THM (STT3) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-1.

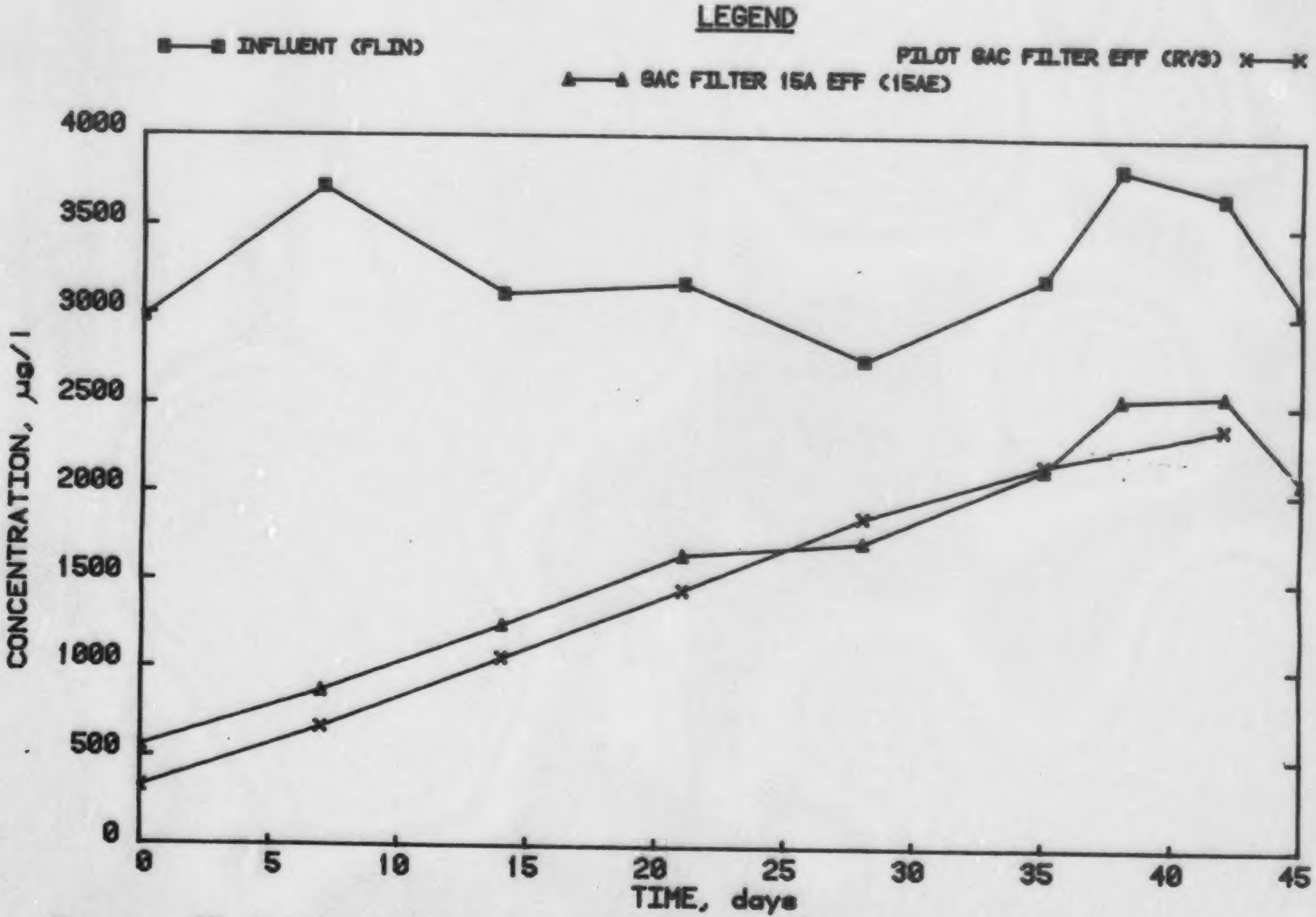


Figure 85. Total organic carbon (TOC) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-1.

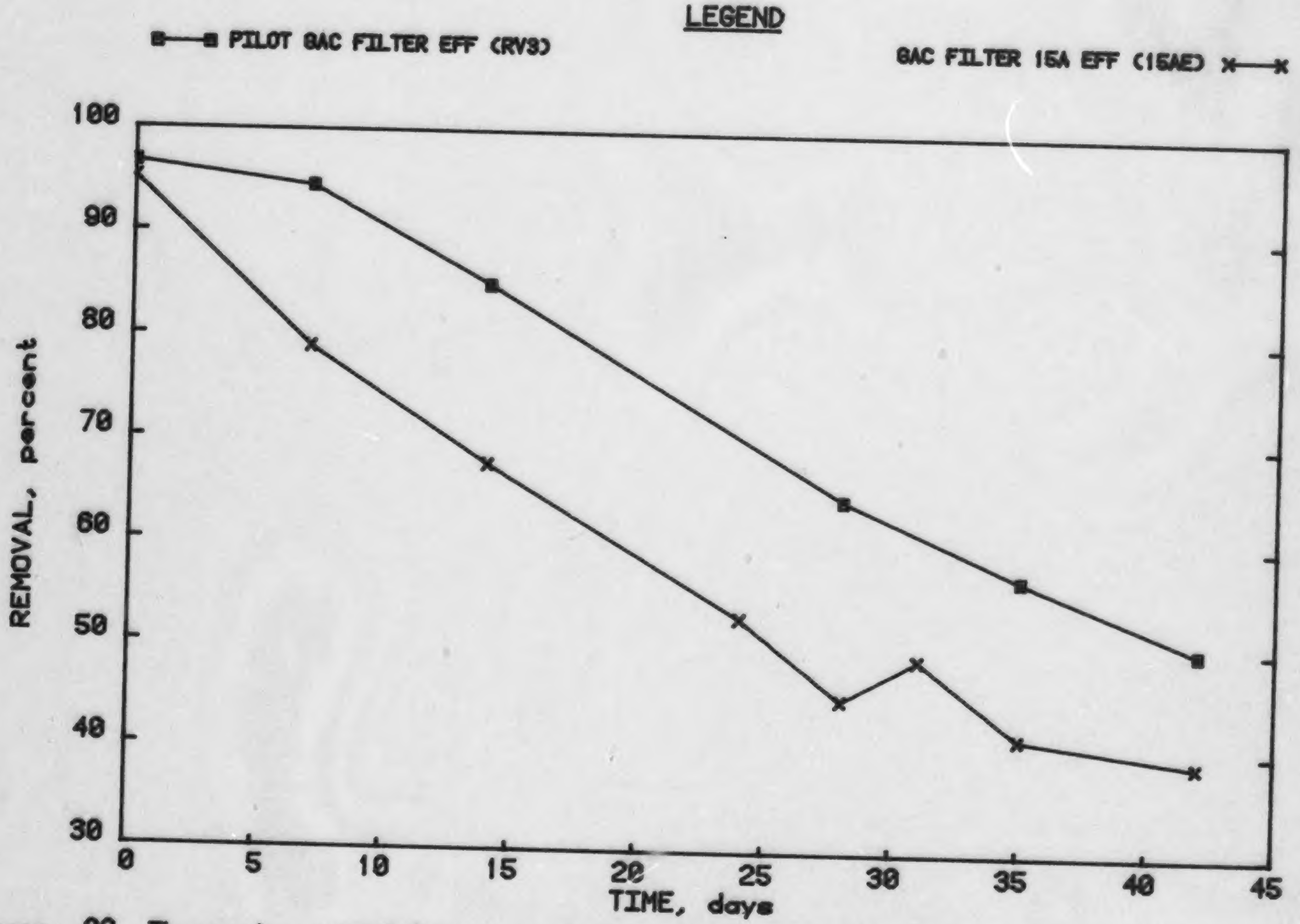


Figure 86. Three-day simulated distribution system THM (STT3) percent removal curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-2.

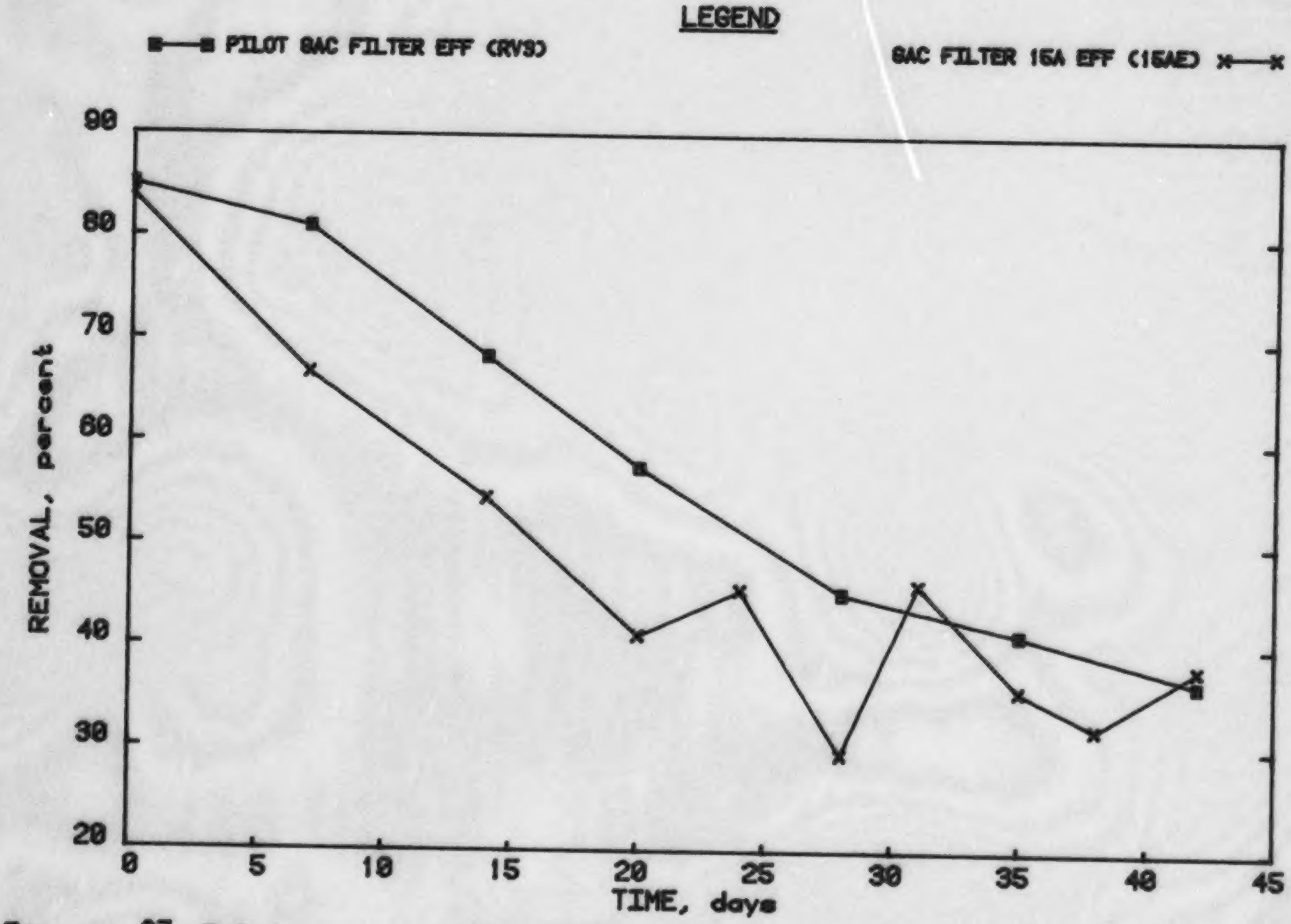


Figure 87. Total organic carbon (TOC) percent removal curves for pilot GAC filter and GAC filter 15A effluents, Phase 3-2.

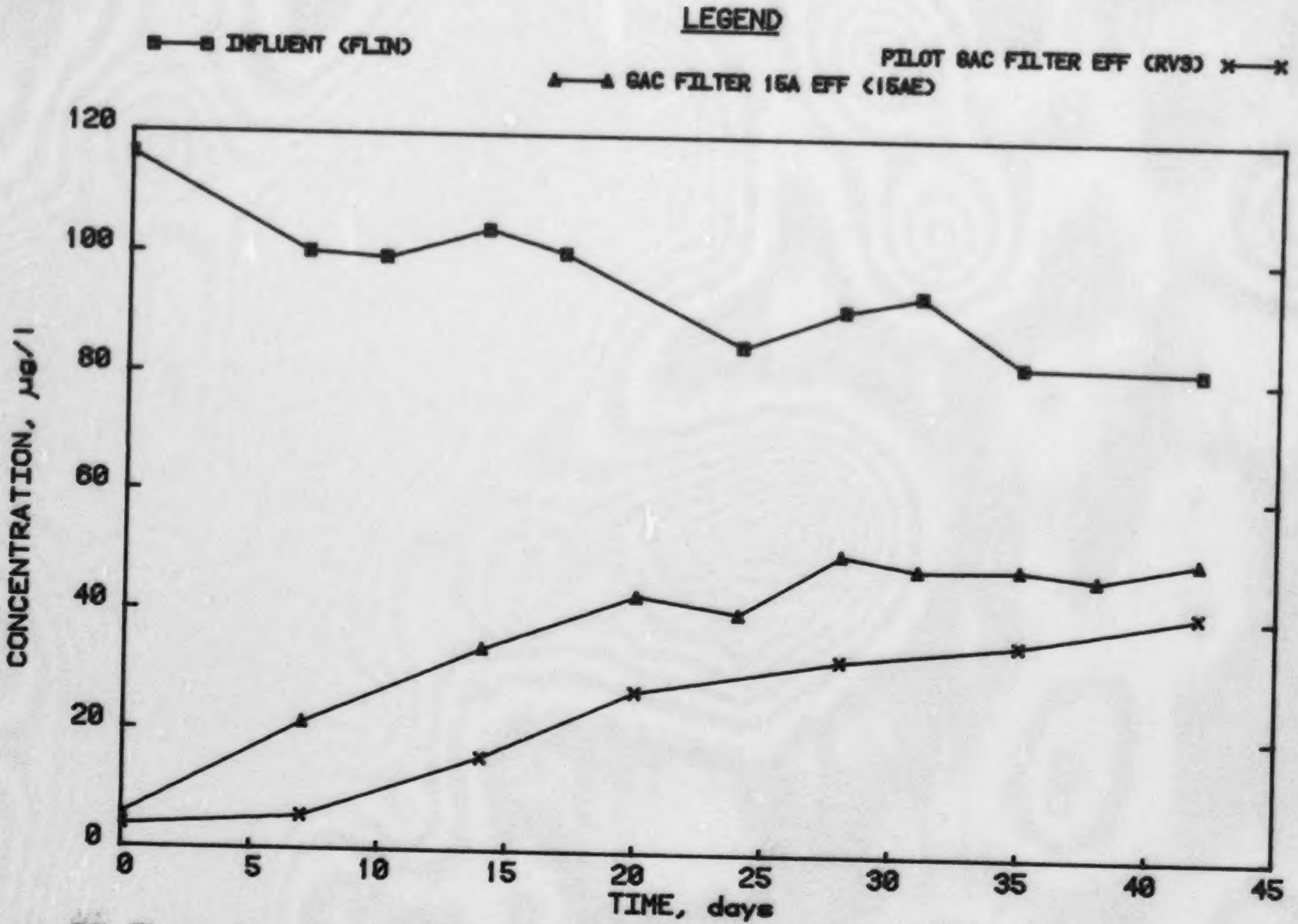


Figure 88. Three-day simulated distribution system THM (STT3) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-2.

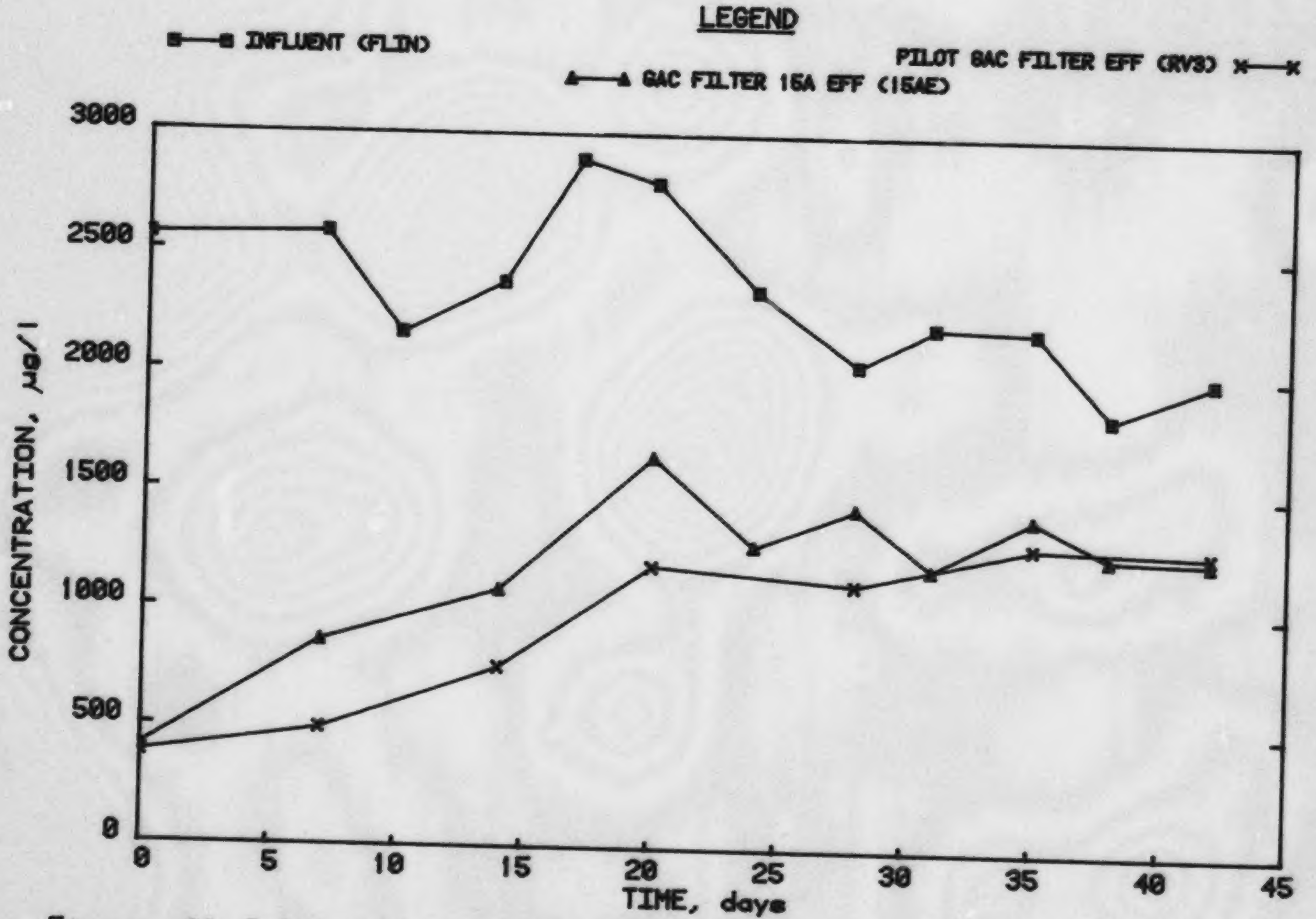


Figure 89. Total organic carbon (TOC) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-2.

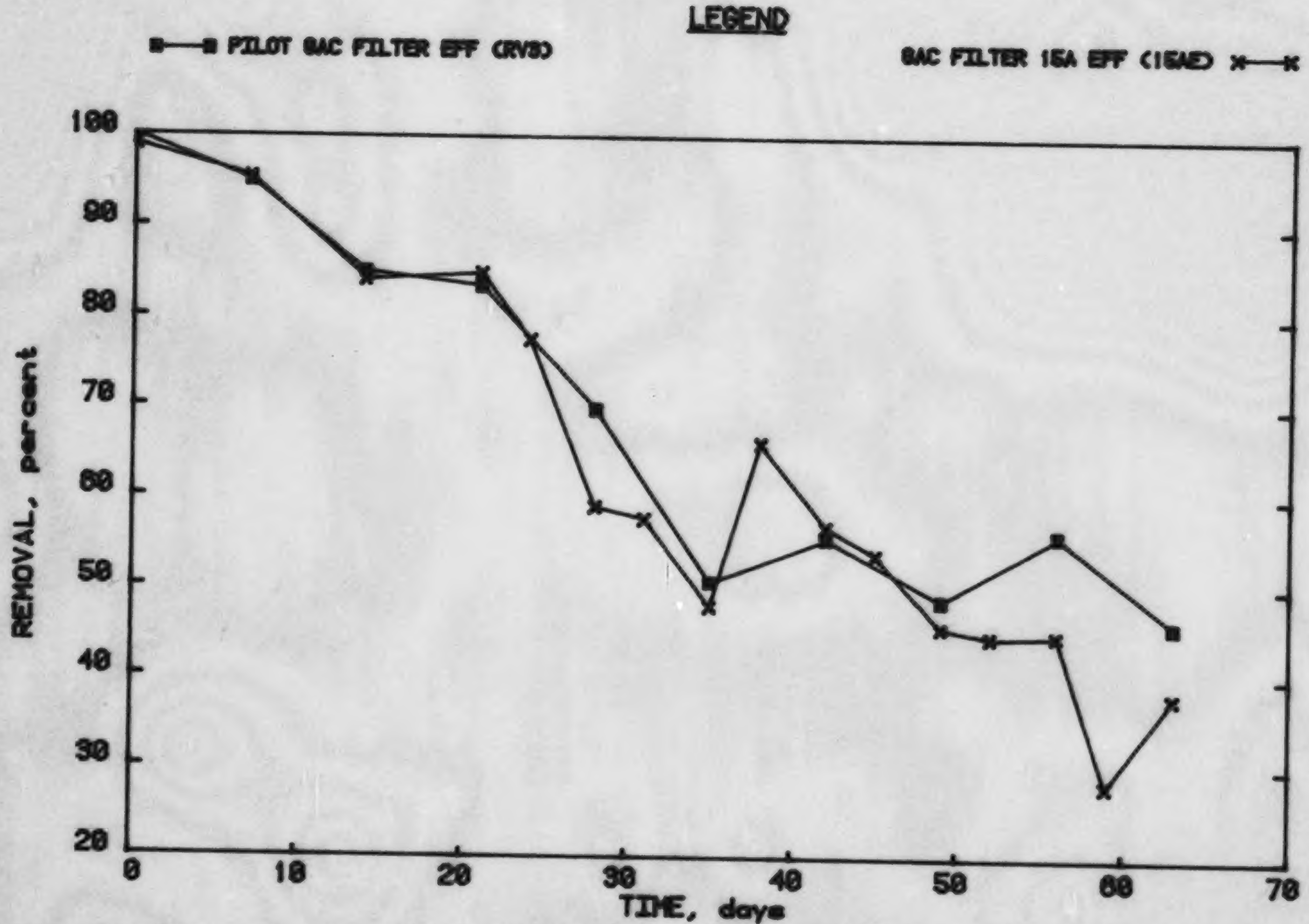


Figure 90. Three-day simulated distribution system THM (STT3) percent removal curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-3.

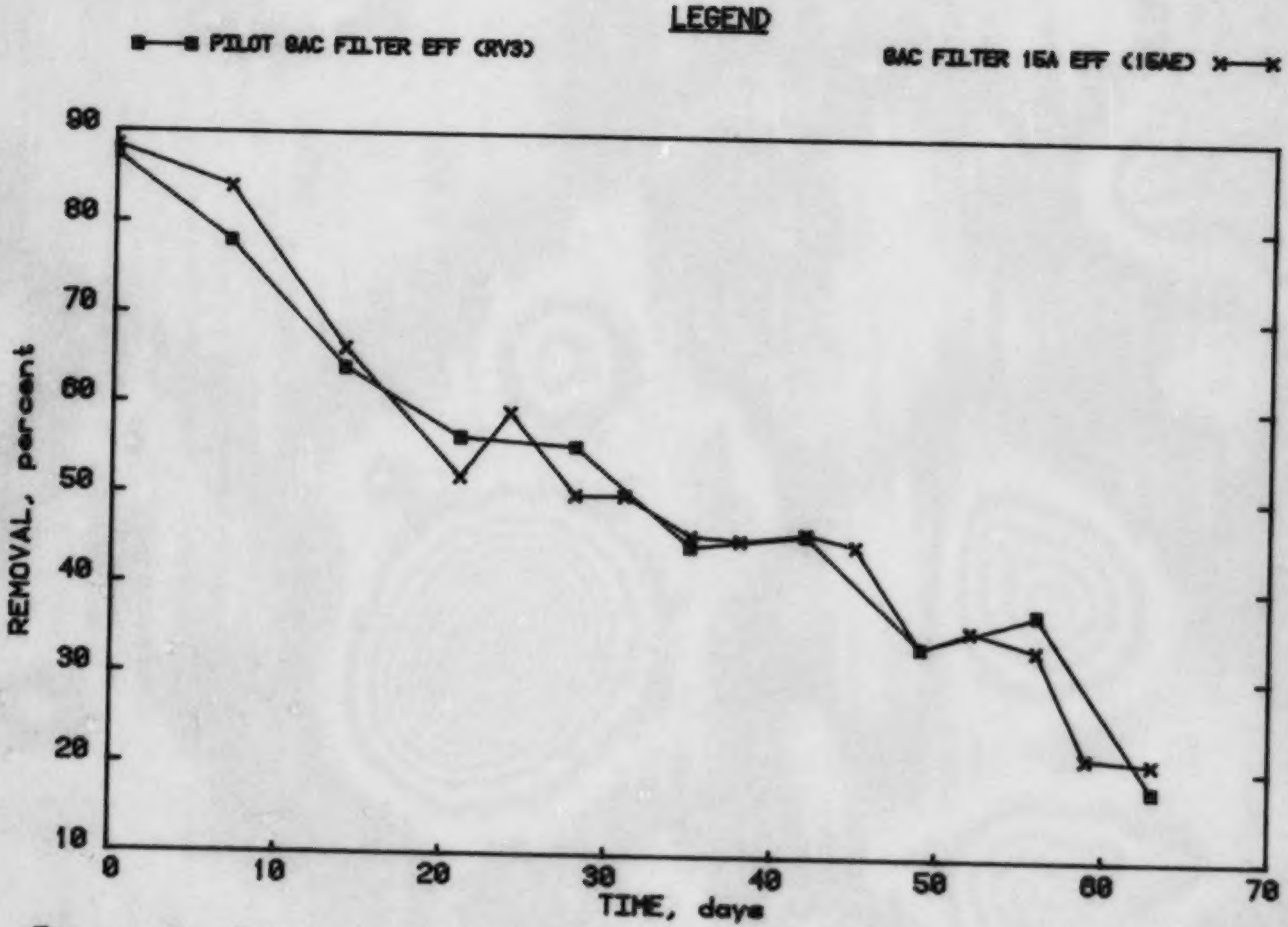


Figure 91. Total organic carbon (TOC) percent removal curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-3.

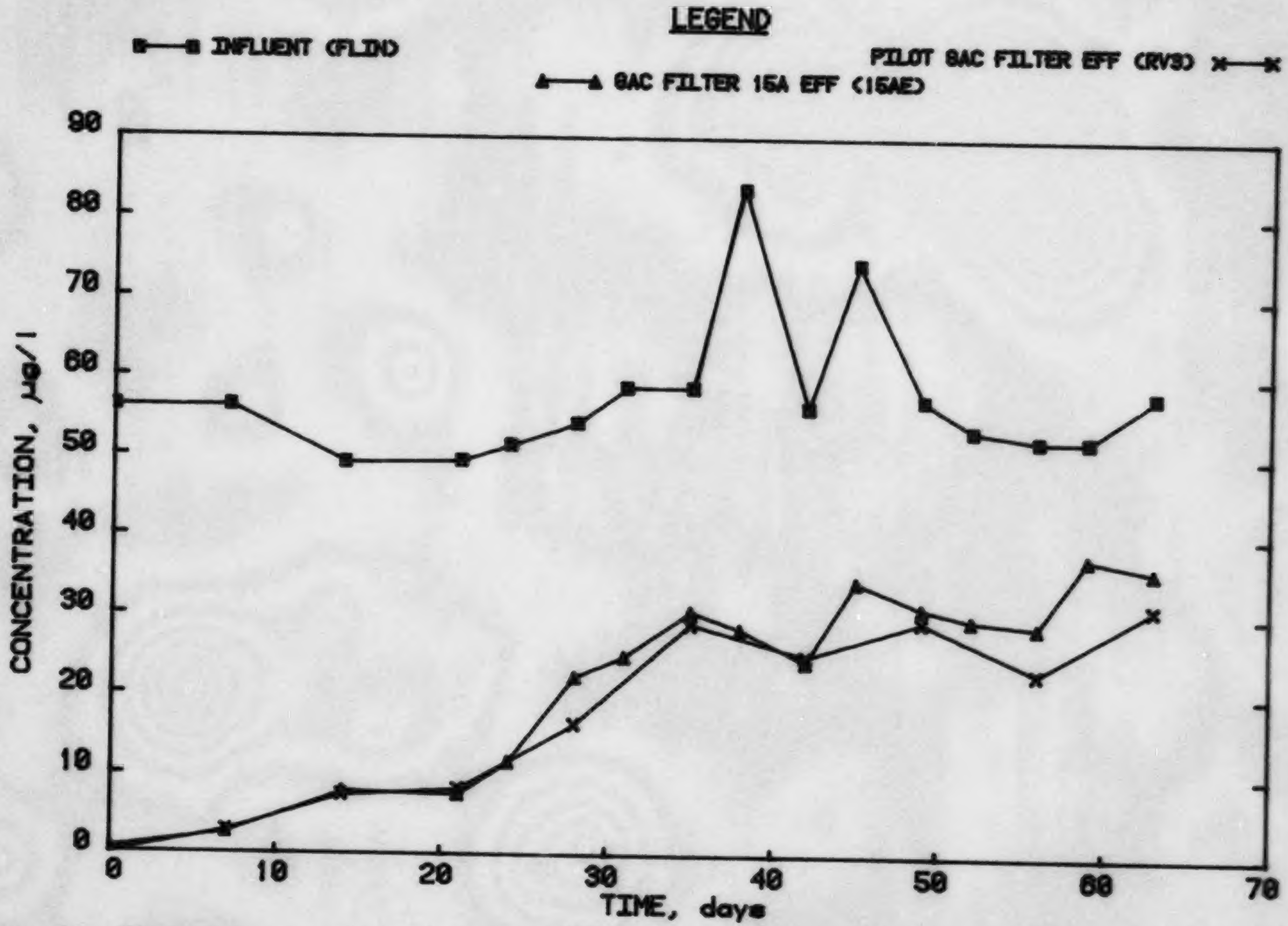


Figure 92. Three-day simulated distribution system THM (STT3) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-3.

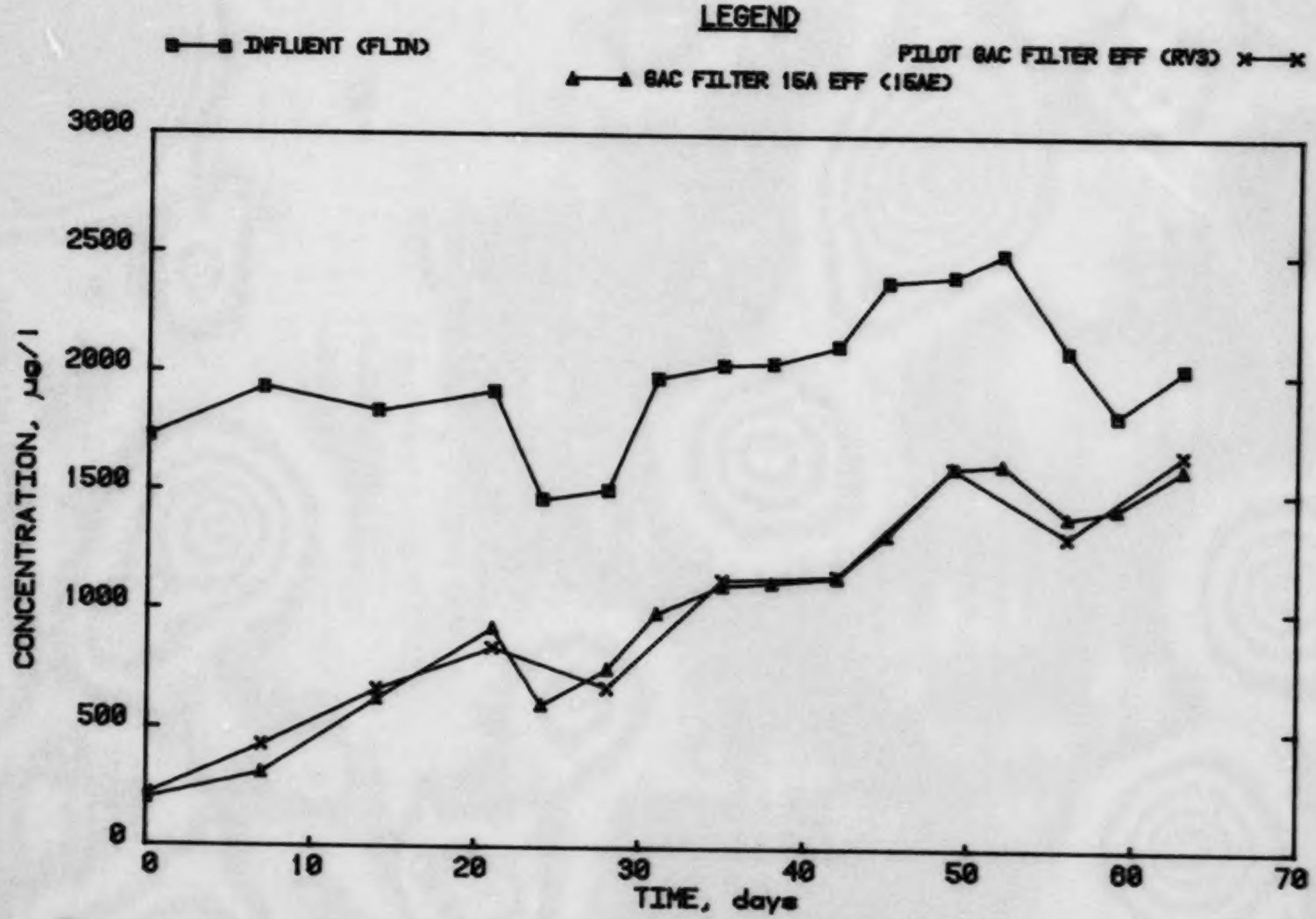


Figure 93. Total organic carbon (TOC) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-3.

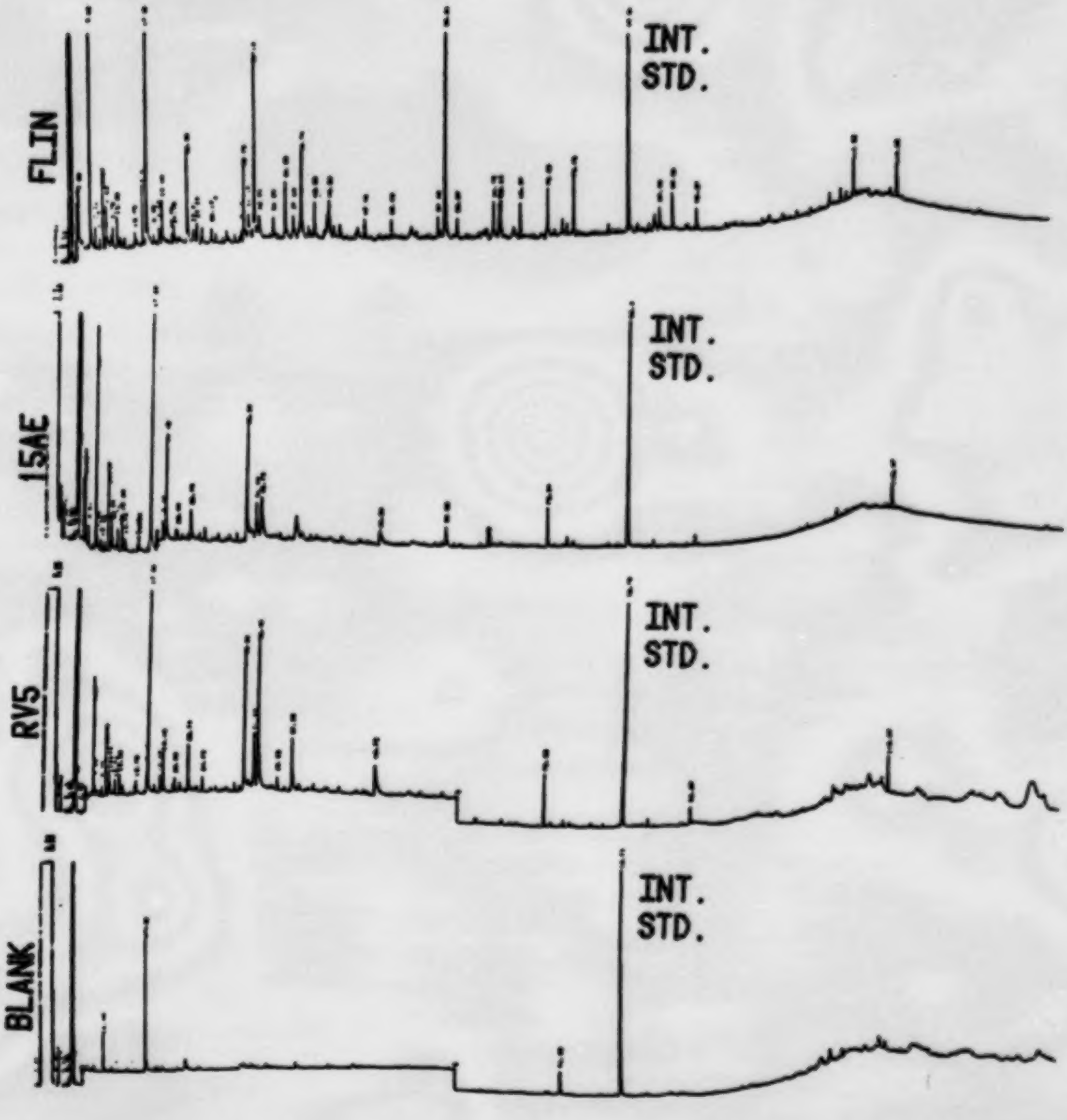


FIGURE 94. Acid extract profiles for GAC Filter 15A and pilot GAC filter, Phase 3-0, runday 57.

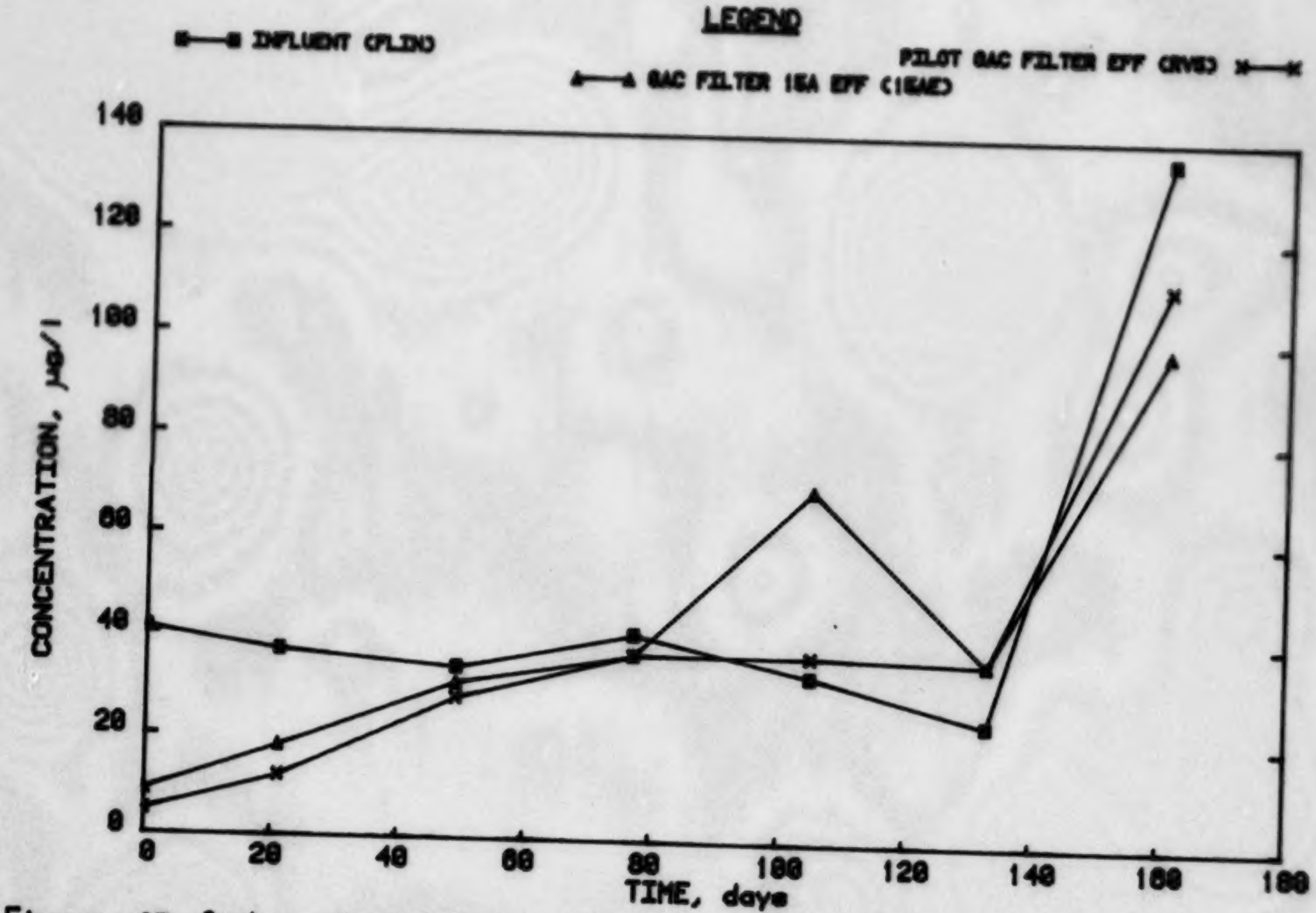


Figure 95. Carbon adsorbable organohalides (CAOX) breakthrough curves for pilot GAC filter and GAC Filter 15A effluents, Phase 3-0.

TABLE 53. COMPARISON OF PILOT AND FULL-SCALE CONTACTOR SYSTEMS

GAC Filter System	Phase-Run	Hydraulic Loading Rate		Exhaustion	
		lpm/sq m	gpm/sq ft	TOC (runday)	THMSIMDIST (runday)
Pilot	3-0	296	7.3	155	197
Full-scale		301	7.4	169	204
Pilot	3-1	289	7.1	85	a
Full-scale		301	7.4	a	a
Pilot	3-2	281	6.9	a	a
Full-scale		301	7.4	a	a

[a] Exhaustion did not occur during life of this run.

(Figures 104 and 105). These graphs show the contactor to be 10% more efficient in removals. As shown in Figures 106 and 107, exhaustion did not occur during this phase.

Based on acid extract GC/FID profiles, it was apparent that there was only a small difference between the two systems in organic removals (Figure 108).

The CAOX data showed that the contactor had a 30% better removal than the pilot system (Figure 109).

The following observations could account for the difference in efficiency between pilot and full-scale systems:

1. The variations in the volume measuring device of the pilot systems.
2. The accuracy of full-scale flow controllers.
3. The pilot GAC filters had flow adjustment problems due to floc buildup and insufficient head to permit accurate flow regulation.
4. The difficulty in measuring weight and volume of GAC in all systems.

Overall, although there were occasionally minor deviations in the results from the pilot and full-scale systems, it was concluded that pilot systems would be sufficiently predictive of full-scale performance to be used for plant design purposes.

Objective 9: GAC Exhaustion Criteria in GAC Filters and Contactors

Identification of a specific indicator of GAC exhaustion turned out to be an impossible task. Several different criteria were evaluated including

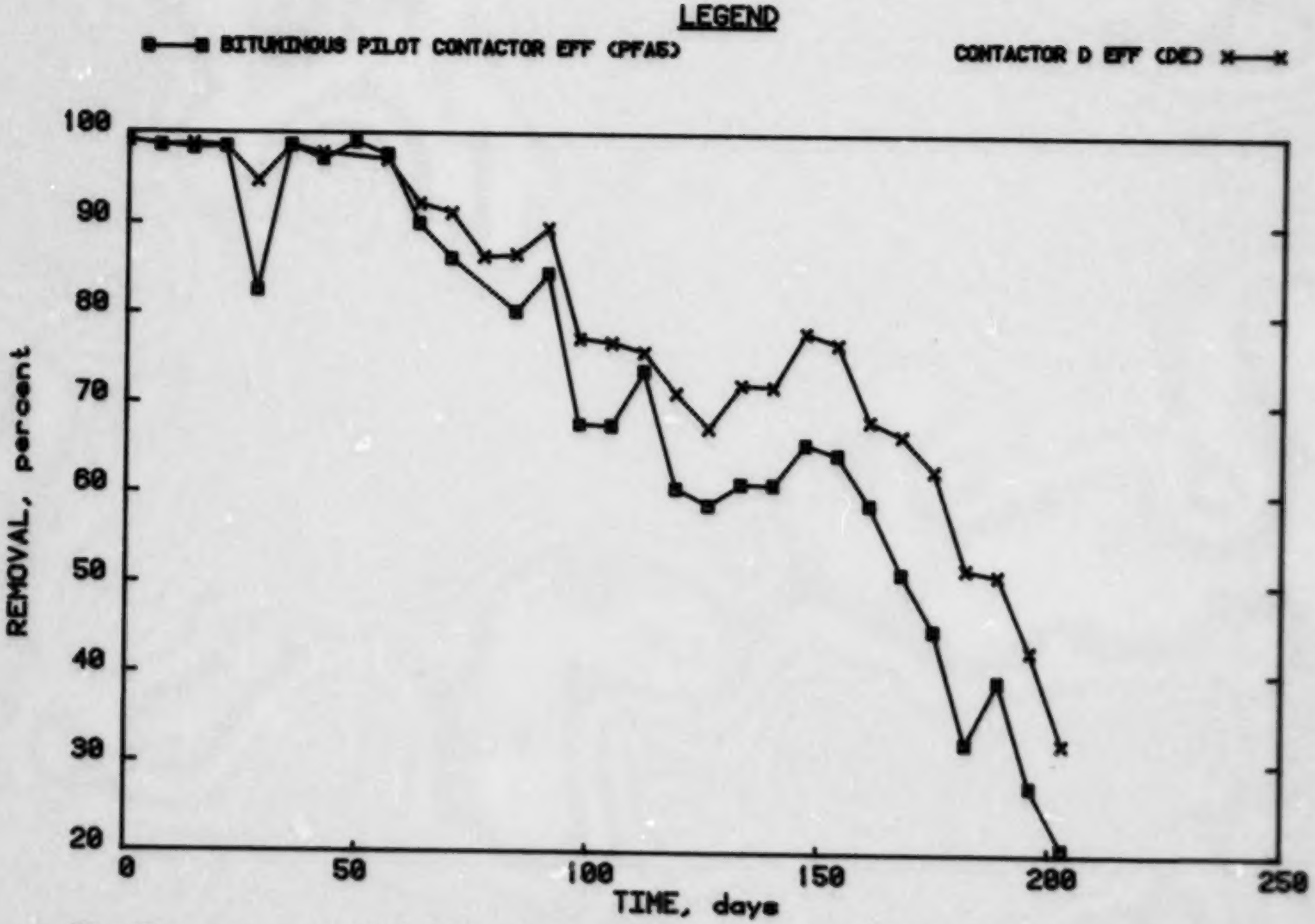


Figure 96. Three-day simulated distribution syst. THM (STT3) percent removal curves for bituminous pilot contactor and Contactor D effluents, Phase 3-0.

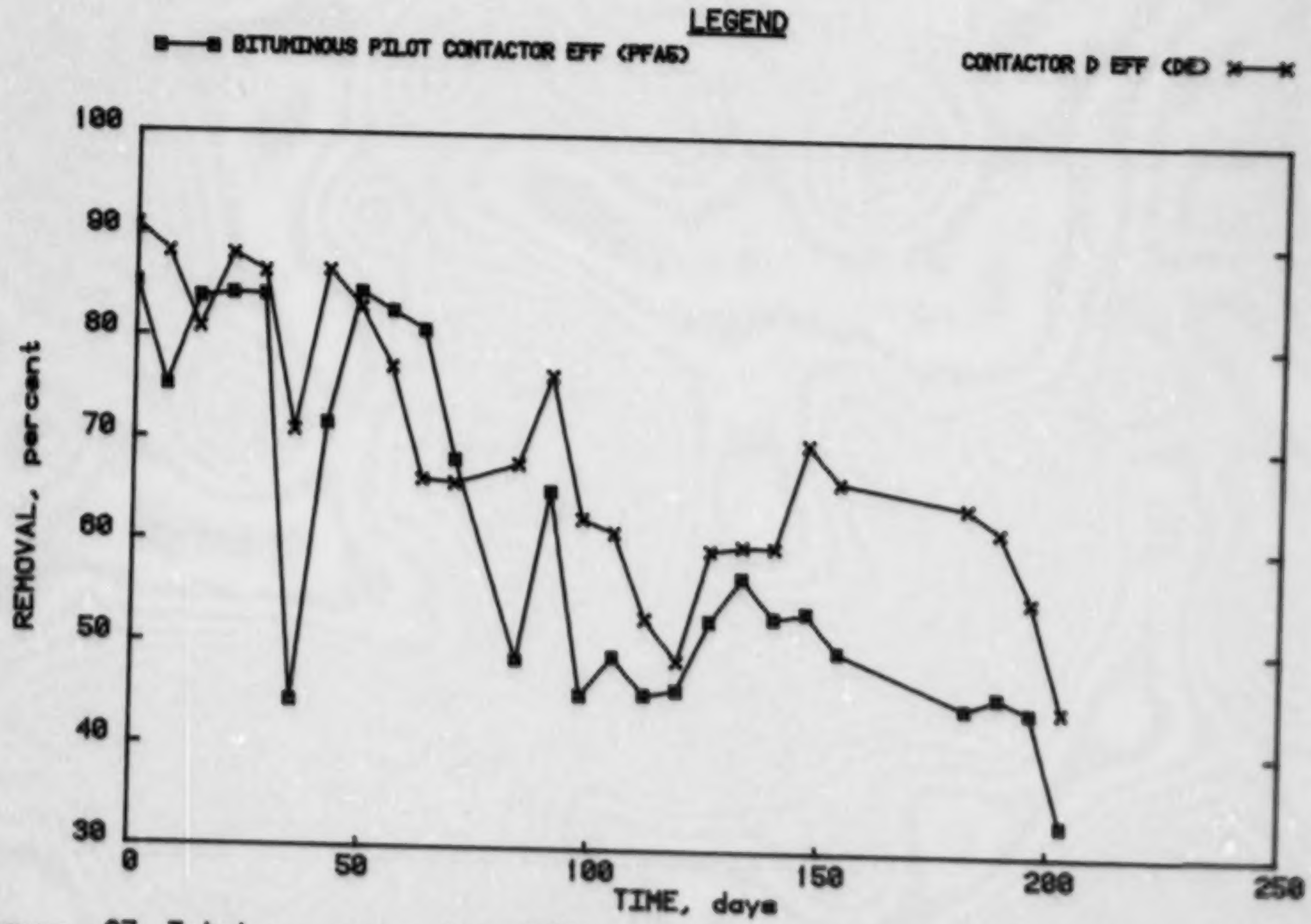


Figure 97. Total organic carbon (TOC) percent removal curves for bituminous pilot contactor and Contactor D effluents, Phase 3-0.

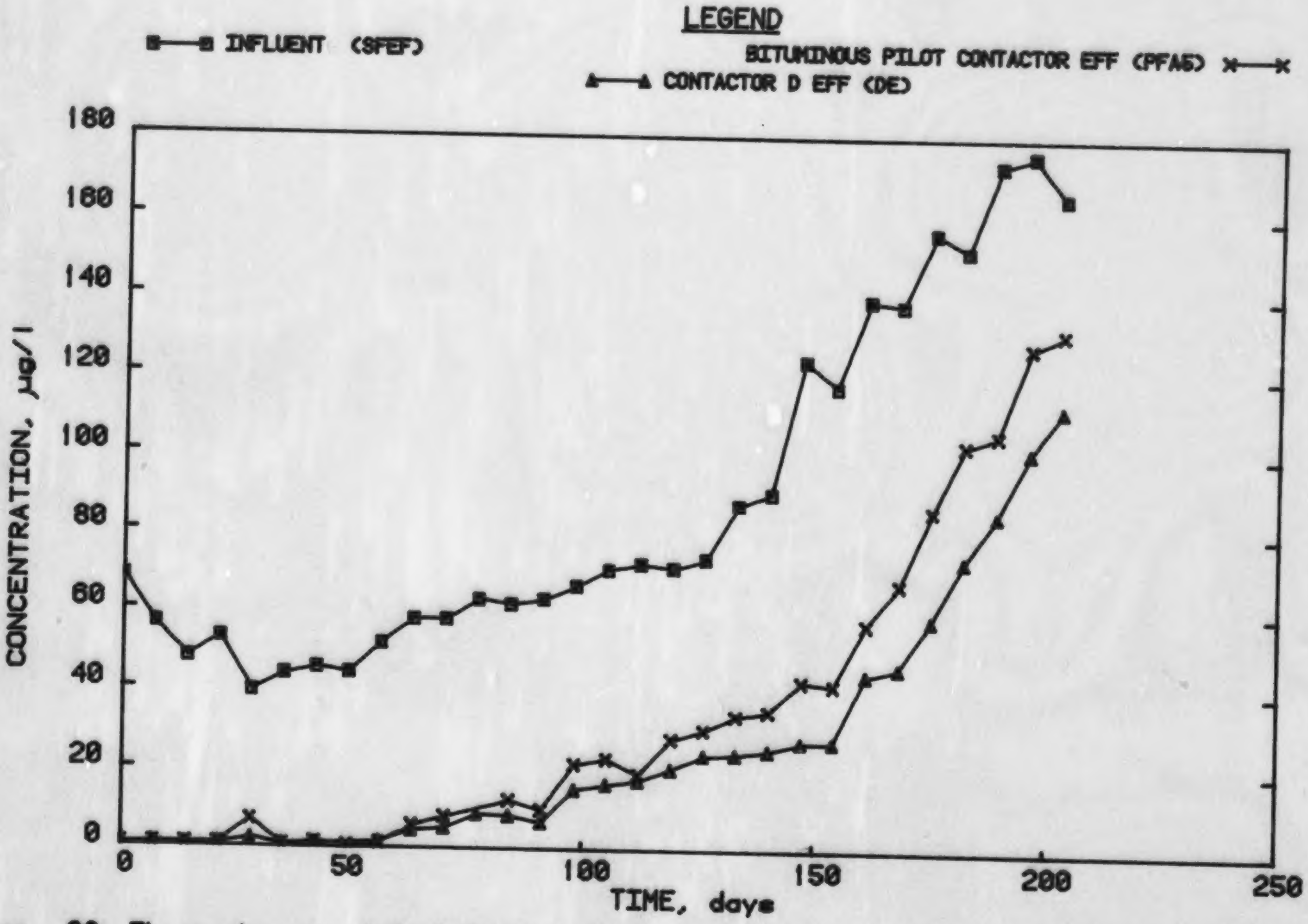


Figure 98. Three-day simulated distribution system THM (STT3) breakthrough curves for bituminous pilot contactor and Contactor D effluents, Phase 3-0.

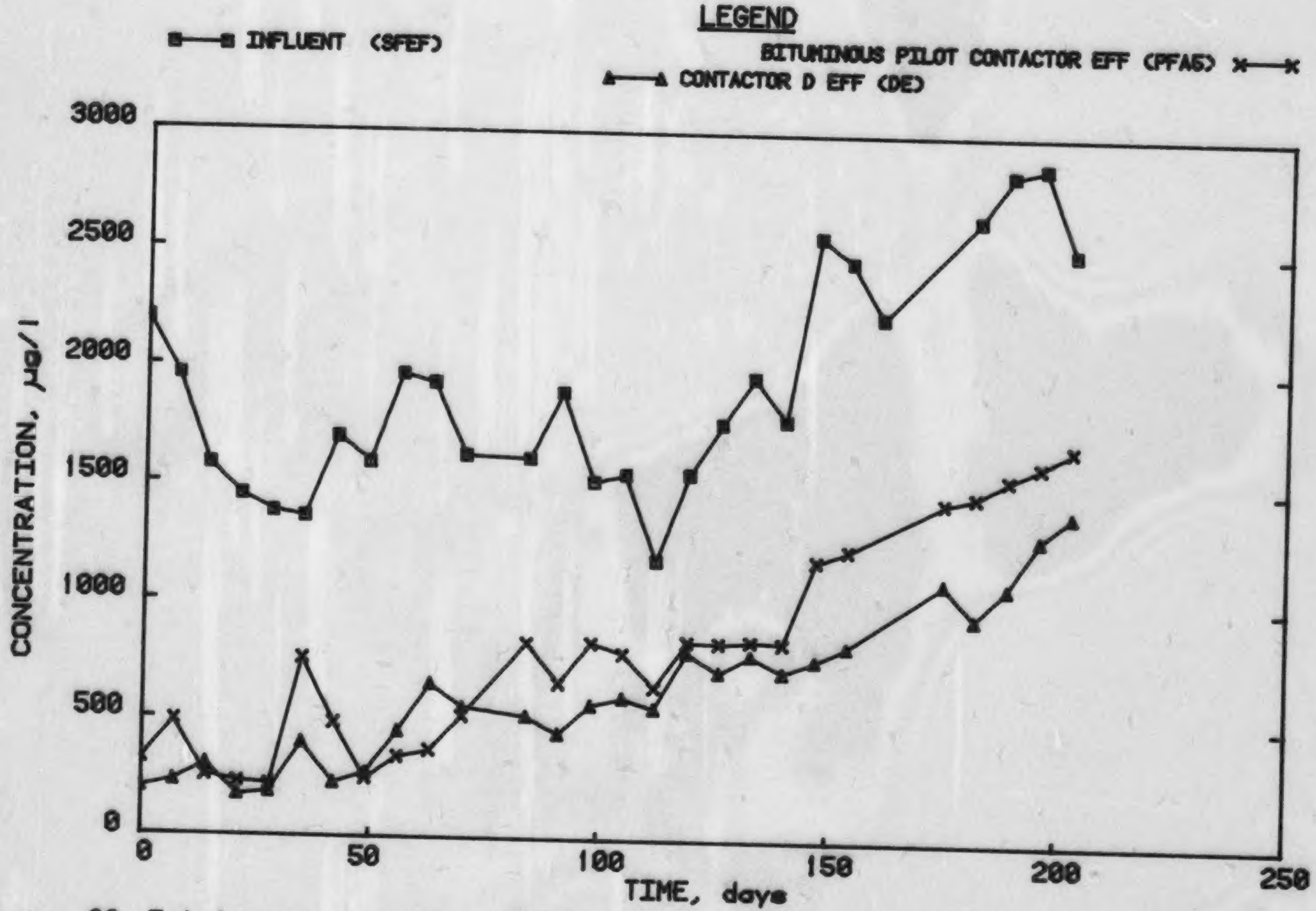


Figure 99. Total organic carbon (TOC) breakthrough curves for bituminous pilot contactor and Contactor D effluents, Phase 3-0.

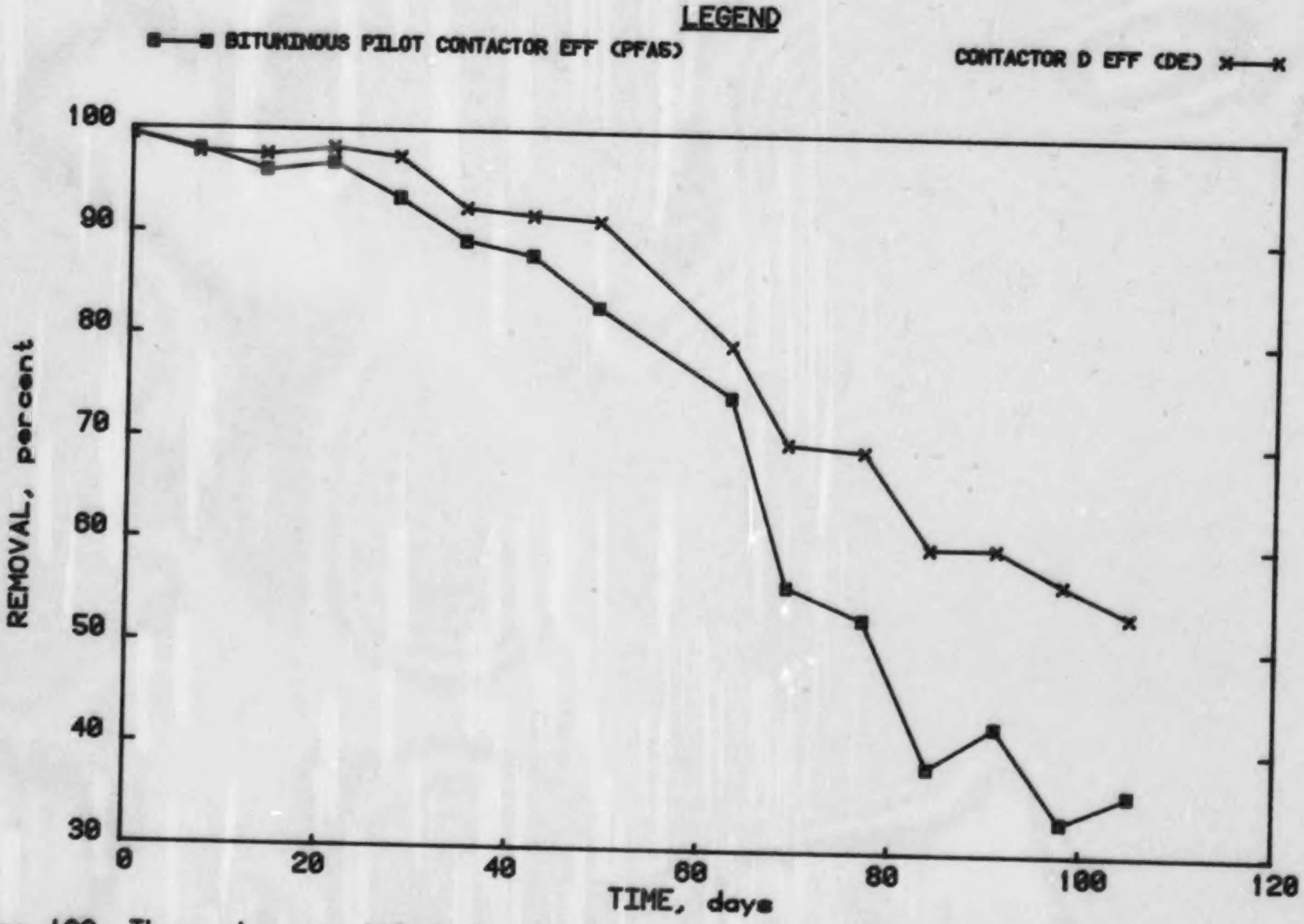


Figure 100. Three-day simulated distribution syst. THM (STT3) percent removal curves for bituminous pilot contactor and Contactor D effluents, Phase 3-1.

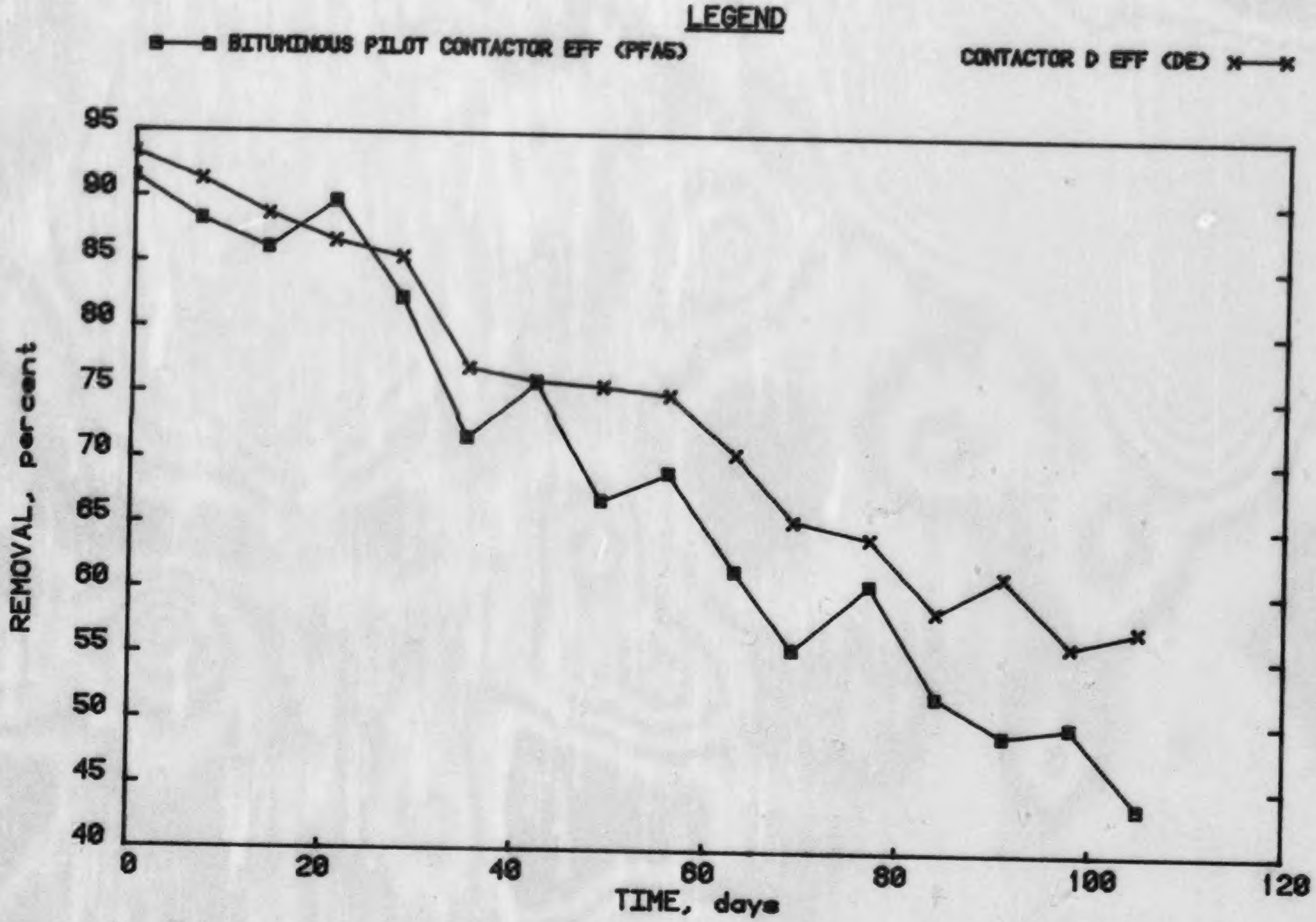


Figure 101. Total organic carbon (TOC) percent removal curves for bituminous pilot contactor and Contactor D effluents, Phase 3-1.

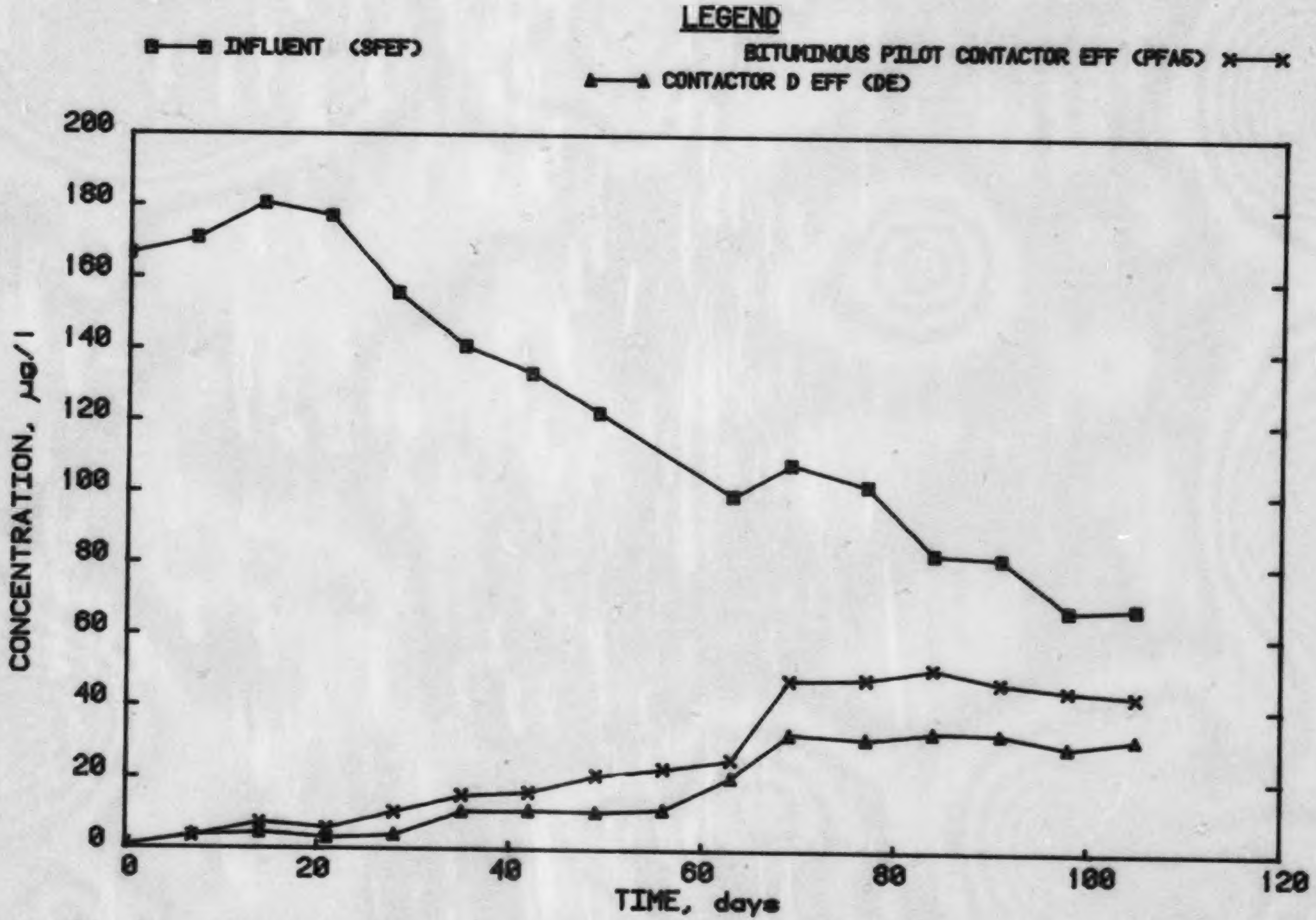


Figure 102. Three-day simulated distribution system THM (STT3) breakthrough curves for bituminous pilot contactor and Contactor D effluents, Phase 3-1.

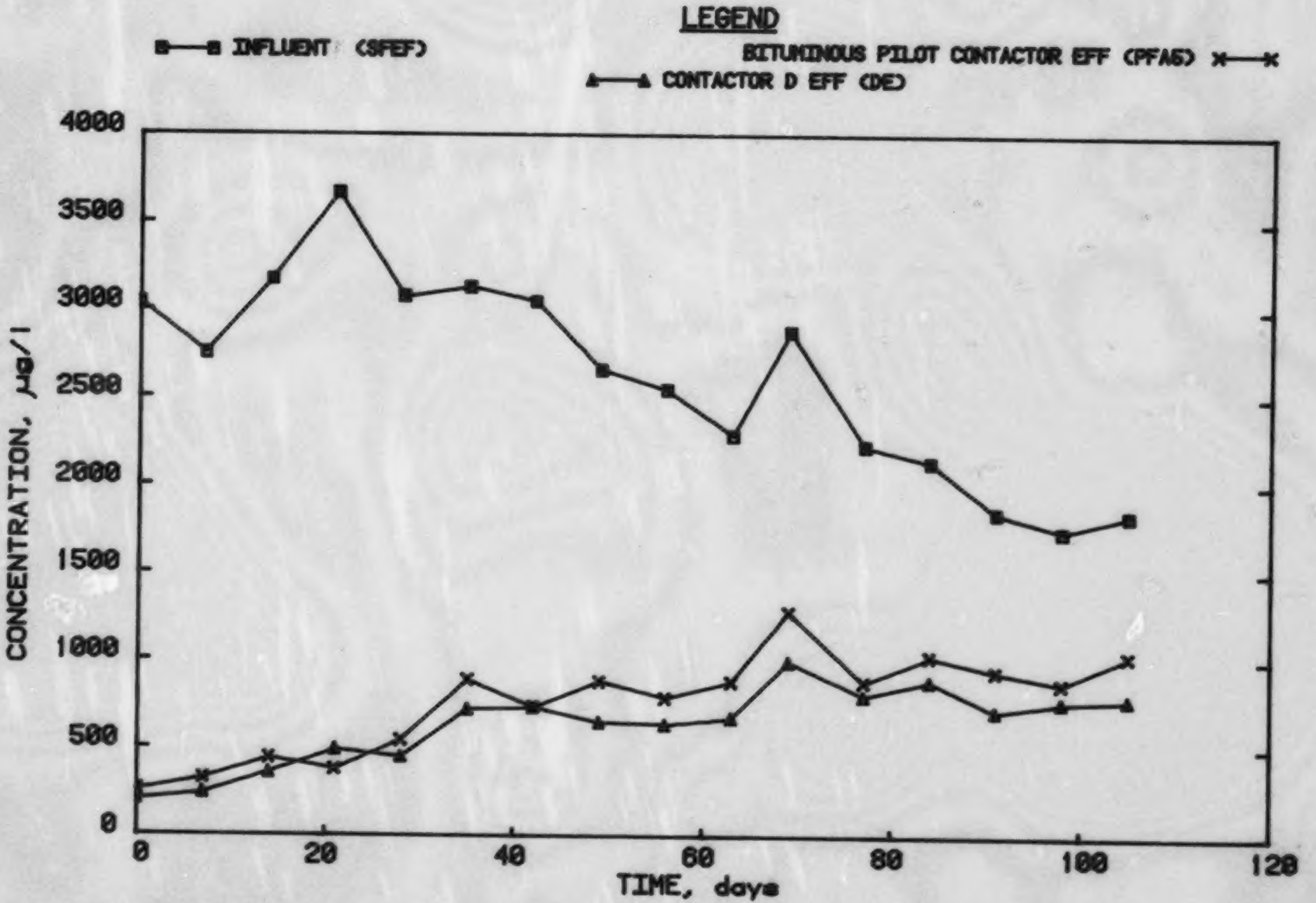


Figure 103. Total organic carbon (TOC) breakthrough curves for bituminous pilot contactor and Contactor D effluents, Phase 3-1.

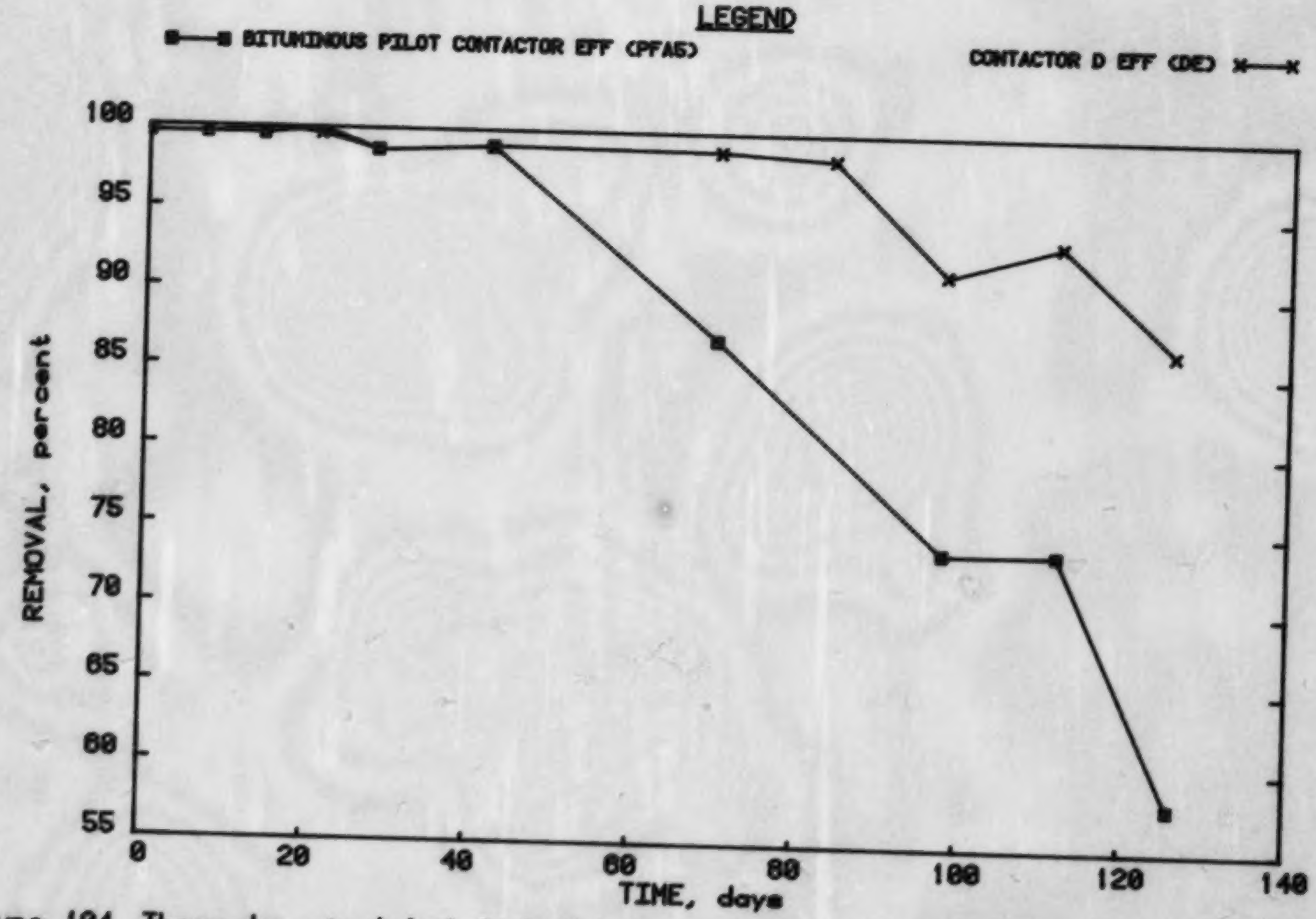


Figure 104. Three-day simulated distribution syst. THM (STT3) percent removal curves for bituminous pilot contactor and Contactor D effluents, Phase 3-2.

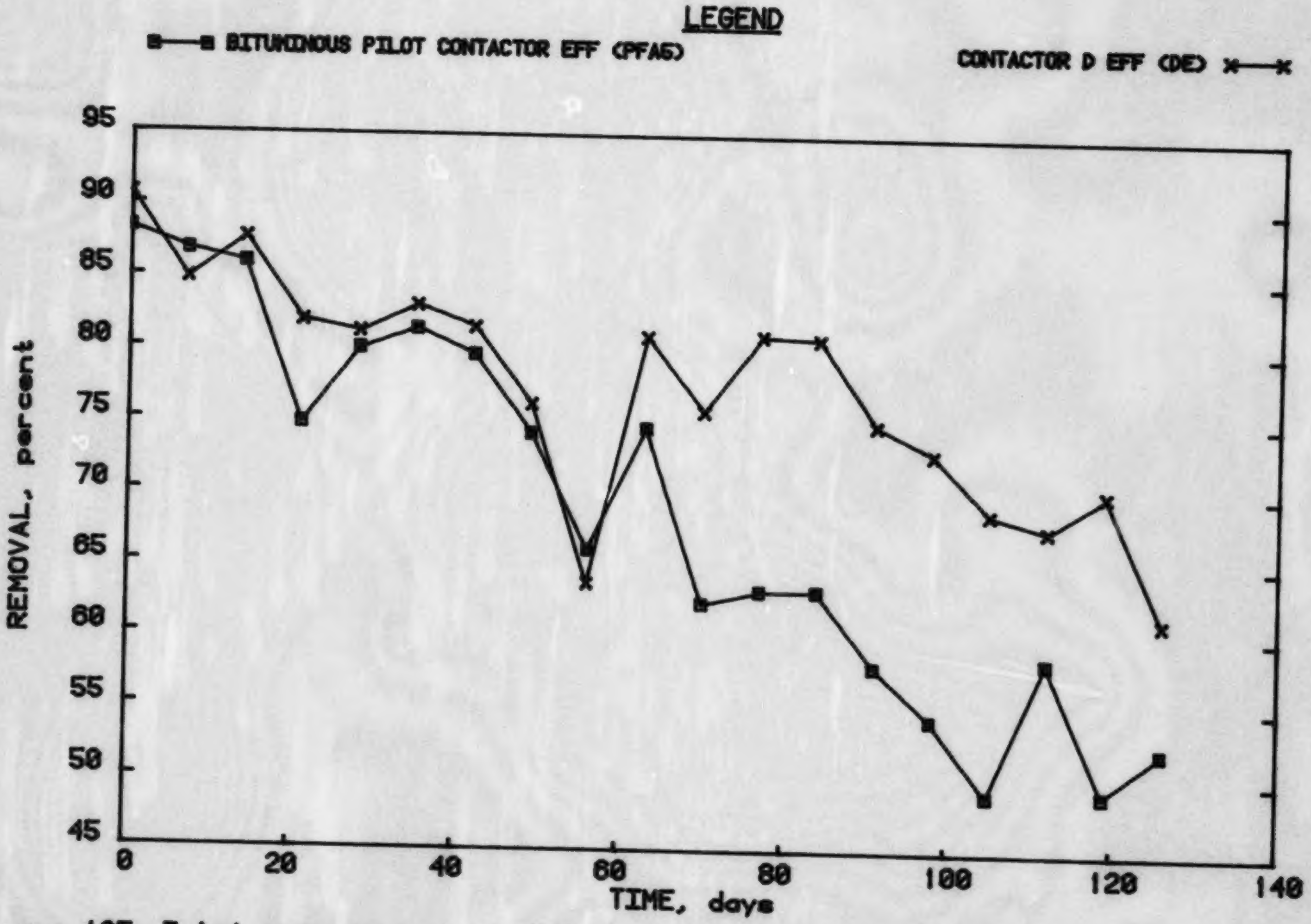


Figure 105. Total organic carbon (TOC) percent removal curves for bituminous pilot contactor and Contactor D effluents, Phase 3-2.

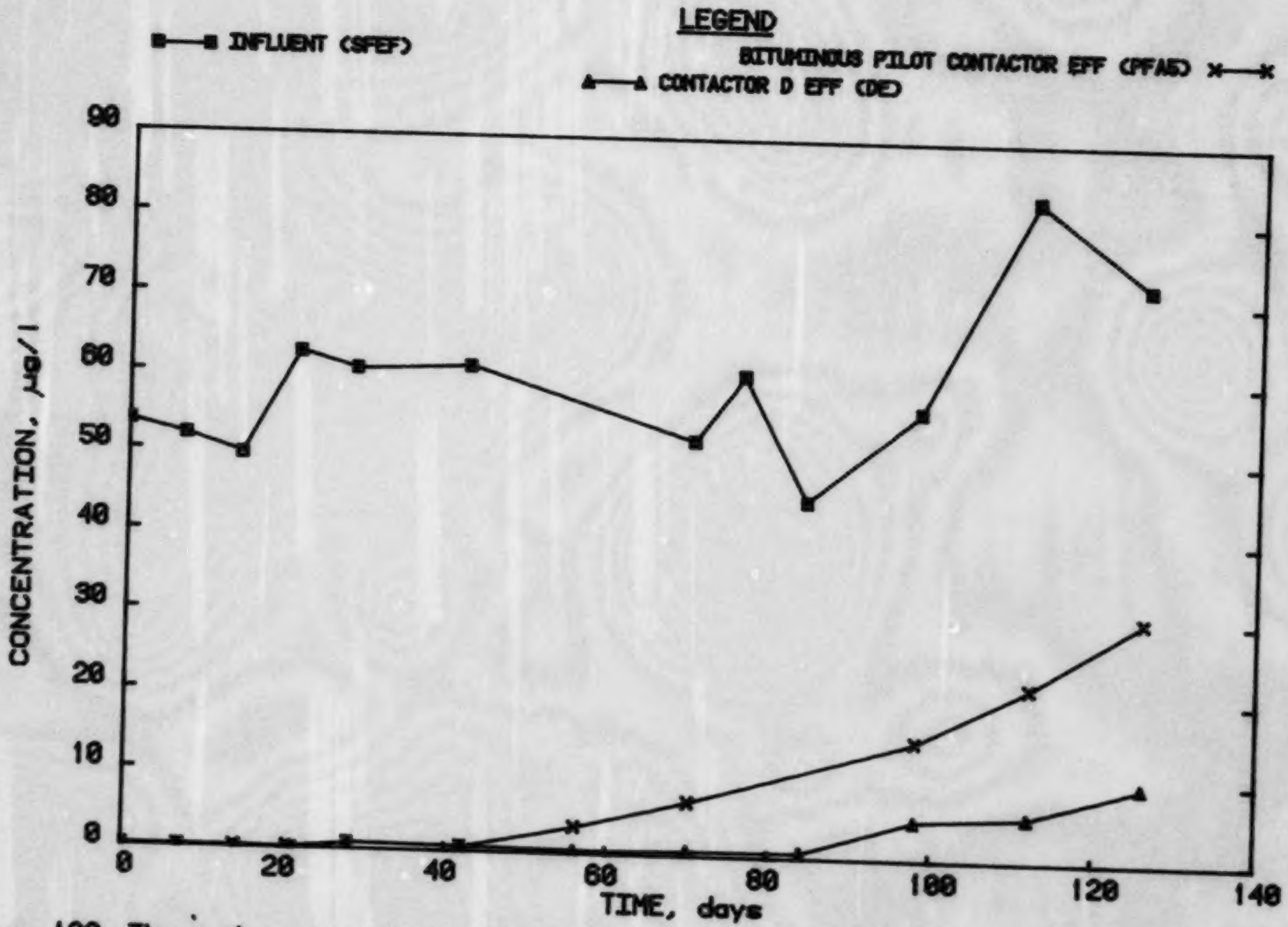


Figure 106. Three-day simulated distribution system THM (STT3) breakthrough curves for bituminous pilot contactor and Contactor D effluents, Phase 3-2.

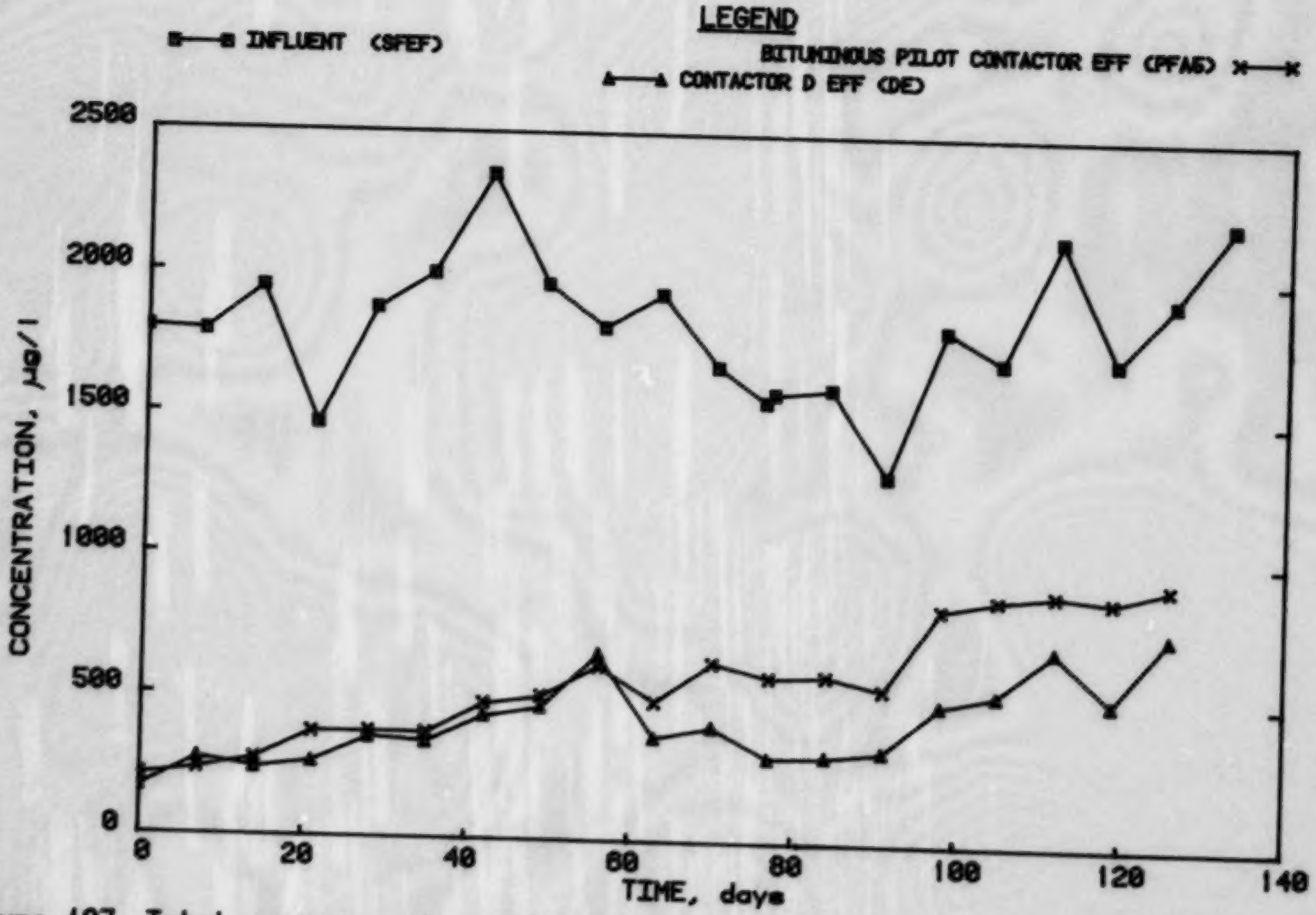


Figure 107. Total organic carbon (TOC) breakthrough curves for bituminous pilot contactor and Contactor D effluents, Phase 3-2.

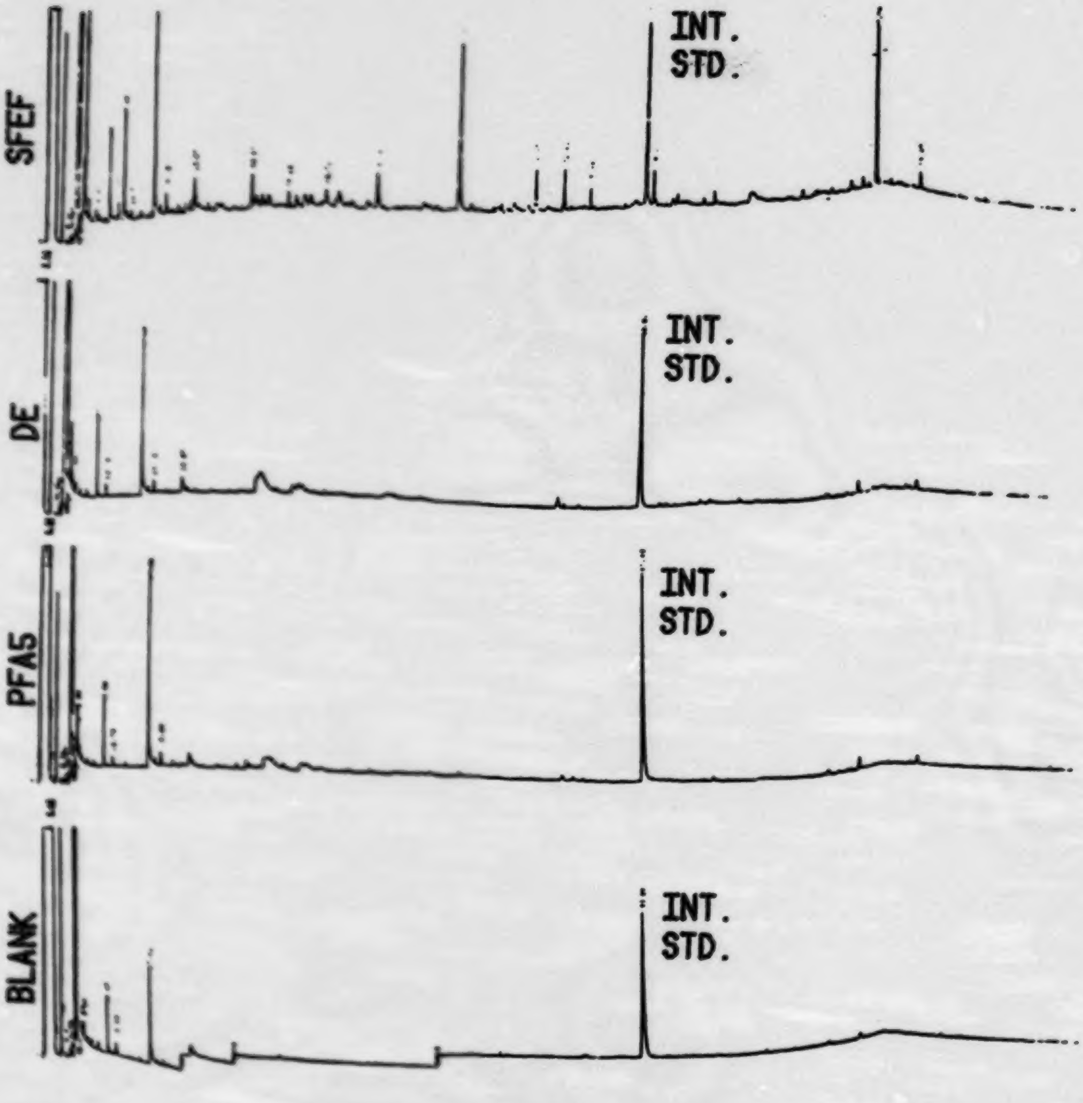


FIGURE 108. Acid extract profiles for Contactor D and pilot contactor, Phase 3-0, runday 113.

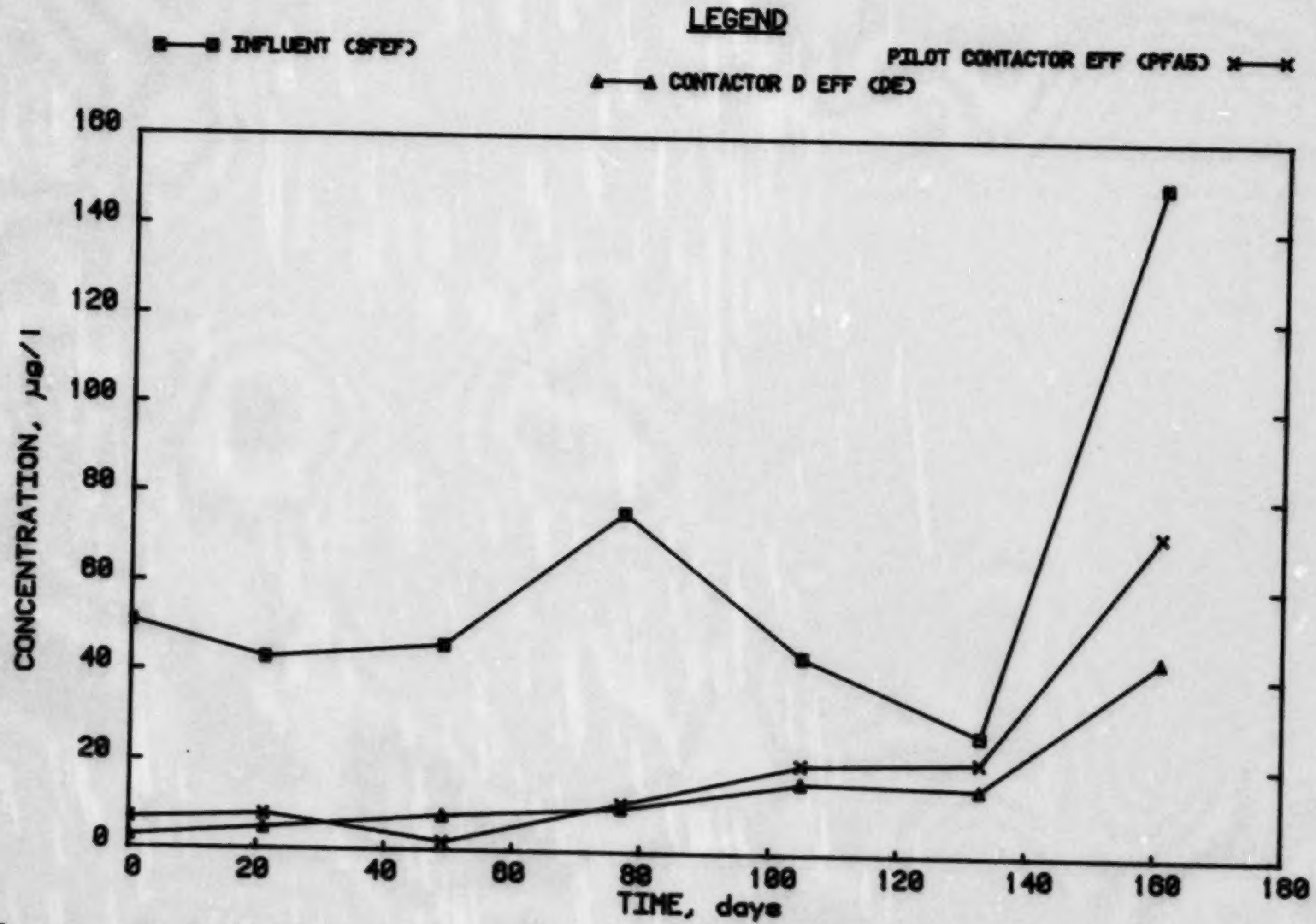


Figure 109. Carbon adsorbable organohalides (CAOX) breakthrough curves for pilot contactor and Contactor D effluents, Phase 3-0.

the three specified in the original GAC treatment requirement of the February 9, 1978 proposed amendments to the Safe Drinking Water Act (SDWA).[26]

A discussion of each of the criteria considered under this objective along with the merits and shortcomings of each will be presented. Major shortcomings of all criteria are that health effects information and more specifically, maximum contaminant levels (MCLs) for harmful substances are practically non-existent. With such MCLs, the GAC would be regenerated when an effluent concentration, for a substance known to be adsorbable by GAC, approached the MCL for that substance.

The best summary solution seemed to be the regeneration of the GAC when an established MCL is approached or when a three-week running average effluent concentration exceeds 1.0 mg/l TOC (1,000 µg/l) or 0.1 mg/l (100 µg/l) THMSIMDIST, whichever occurs first.

Although INSTTHM and THMFP were also considered for exhaustion criteria, they did not appear to be as useful as the TOC and THMSIMDIST criteria. INSTTHM continues to form beyond the treatment process. THMFP represents the reaction of all precursor with chlorine resulting in THM concentrations far greater than those experienced in the distribution system and, therefore, was not an appropriate criterion. THMSIMDIST would more accurately reflect the distribution system THM concentrations.

There are some full-scale practical matters to consider with any exhaustion criterion. In a large plant, such as the CWW with 47 filters or an equivalent amount of contactors, one would not regenerate all GAC systems at one time. Further, it would be practically impossible to handle the sampling load required from each filter. Therefore, banks of filters or contactors would have to be treated as units and whenever the exhaustion criterion was approached the entire unit would be regenerated.

During the research project, the CWW selected a three-month cycle for contactor and a six-week cycle for filter regeneration based on USEPA data and Phases 1 and 2 data. Although this seemed to be the optimum regeneration frequency, special attention was given at the close of these time frames to the organic data, so that temperature, seasonal influent concentration levels, and other considerations could be used to determine the best time to remove each system for regeneration. Often, in attempting to evaluate various exhaustion criteria and also due to the unavailability of the regeneration furnace, systems were left on line past exhaustion. Occasionally in the later stages of the grant, systems were taken off early to gain regeneration experience and GAC loss data.

Exhaustion Criteria--

Tables 54 through 56 show the results of applying each criterion discussed below. Criteria 1 through 3 are contained in the proposed rules for the GAC treatment technique as published in the Federal Register[26] (as "design" criteria, not necessarily as "exhaustion" criteria). However, they were evaluated herein as "exhaustion" criteria.

TABLE 54. APPLICATION OF VARIOUS EXHAUSTION (EXH) CRITERIA TO GAC FILTER 15A AND CONTACTOR D, PHASE 3-0

Data Description	TOC 0.5 mg/l	TOC 1.0 mg/l	TOC 1.2 mg/l	TOC 1.5 mg/l	TOC % Removal (Steady State)	STT3 0.1 mg/l	TOC Loading Retained 75%	TOC 50% Removal
GAC Filter 15A								
Time to EXH, days	57	57	64	127	29	169	8	50
Effluent Conc., mg/l	1.5	1.5	1.4	1.6	0.7	0.11	0.7	0.9
Removal, %	30	30	37	13	52	16	66	40
Loading, kg	1,045	1,045	1,141	1,567	642	84	243	961
Loading Retained, %	55	55	53	37	67	38	75	59
Loading/GAC Wt., g/kg	24.2	24.2	26.4	36.3	14.9	1.9	5.6	22.2
TOC Conc. @ STT3, EXH, mg/l	-	-	-	-	-	a	-	-
STT3 Conc. @ TOC EXH, mg/l	0.03	0.03	0.03	0.05	0.01	-	0.01	0.02
Contactor D								
Time to EXH, days	134	176	a	a	50	a	120	120
Effluent Conc., mg/l	0.8	1.1	-	-	0.3	-	0.8	0.8
Removal, %	60	57	-	-	83	-	49	49
Loading, kg	602	824	-	-	259	-	548	548
Loading Retained, %	72	69	-	-	85	-	74	74
Loading/GAC Wt., g/kg	30.4	41.6	-	-	13.1	-	27.6	27.6
TOC Conc. @ STT3 EXH, mg/l	-	-	-	-	-	-	-	-
STT3 Conc. @ TOC EXH, mg/l	0.02	0.06	-	-	0.00	-	0.02	0.02

[a] Exhaustion criterion was not met during this run.

TABLE 55. APPLICATION OF VARIOUS EXHAUSTION (EXH) CRITERIA TO GAC FILTER 15A AND CONTACTOR D, PHASE 3-1

Data Description	TOC 0.5 mg/l	TOC 1.0 mg/l	TOC 1.2 mg/l	TOC 1.5 mg/l	TOC % Removal (Steady State)	STT3 0.1 mg/l	TOC Loading Retained 75%	TOC 50% Removal
GAC Filter 15A								
Time to EXH, days	22	22	22	29	29	36	15	29
Effluent Conc., mg/l	1.6	1.6	1.6	1.7	1.7	0.12	1.2	1.7
Removal, %	48	48	48	38	38	30	60	38
Loading, kg	919	919	919	1,088	1,088	72	694	1,088
Loading Retained, %	68	68	68	62	62	60	74	62
Loading/GAC Wt., g/kg	20.6	20.6	20.6	24.4	24.4	27.6	15.6	24.4
TOC Conc. @ STT3 EXH, mg/l	-	-	-	-	-	2.1	-	-
STT3 Conc. @ TOC EXH, mg/l	0.09	0.09	0.09	0.12	0.12	-	0.06	0.12
Contactor D								
Time to EXH, days	70	a	a	a	29	a	a	a
Effluent Conc., mg/l	1.0	-	-	-	0.4	-	-	-
Removal, %	65	-	-	-	85	-	-	-
Loading, kg	632	-	-	-	305	-	-	-
Loading Retained, %	81	-	-	-	89	-	-	-
Loading/GAC Wt., g/kg	32.0	-	-	-	15.4	-	-	-
TOC Conc. @ STT3 EXH, mg/l	-	-	-	-	-	-	-	-
STT3 Conc. @ TOC EXH, mg/l	0.03	-	-	-	0.00	-	-	-

[a] Exhaustion criterion was not met during this run.

TABLE 56. APPLICATION OF VARIOUS EXHAUSTION (EXH) CRITERIA TO GAC FILTER 15A AND CONTACTOR D, PHASE 3-2

Data Description	TOC 0.5 mg/l	TOC 1.0 mg/l	TOC 1.2 mg/l	TOC 1.5 mg/l	TOC % Removal (Steady State)	STT3 0.1 mg/l	TOC Loading Retained 75%	TOC 50% Removal
GAC Filter 15A								
Time to EXH, days	21	25	25	a	21	a	15	21
Effluent Conc., mg/l	1.6	1.3	1.3	-	1.6	-	1.1	1.6
Removal, %	41	46	46	-	41	-	54	41
Loading, kg	626	710	710	-	626	-	488	626
Loading Retained, %	63	60	60	-	63	-	69	63
Loading/GAC Wt., g/kg	13.1	14.9	14.9	-	13.1	-	10.2	13.1
TOC Conc. @ STT3 EXH, mg/l	-	-	-	-	-	-	-	-
STT3 Conc. @ TOC EXH, mg/l	0.04	0.04	0.04	-	0.04	-	0.03	0.04
Contactor D								
Time to EXH, days	a	a	a	a	43	a	a	a
Effluent Conc., mg/l	-	-	-	-	0.4	-	-	-
Removal, %	-	-	-	-	82	-	-	-
Loading, kg	-	-	-	-	255	-	-	-
Loading Retained, %	-	-	-	-	84	-	-	-
Loading/GAC Wt., g/kg	-	-	-	-	12.8	-	-	-
TOC Conc. @ STT3 EXH, mg/l	-	-	-	-	-	-	-	-
STT3 Conc. @ TOC EXH, mg/l	-	-	-	-	0.00	-	-	-

[a] Exhaustion criterion was not met during this run.

1. The concentration in the effluent of any of the volatile halogenated organic compounds (except the THMs) shall not exceed 0.5 µg/l.

The discussion in the proposed rules supporting this criterion concluded that the presence of these chemicals would also be indicative of the presence of other potentially hazardous substances which would be more difficult to detect. The validity of this surrogate is open to debate.

This criterion has the advantage of being, in some sense, an MCL and is one that the CWW found no problem with meeting even without GAC. The concentration of volatile halogenated organic compounds in excess of this limit were seldom detected even in the raw water before any treatment. The shortcomings of this criterion include the fact that some volatile halogenated organic compounds may be more hazardous than others and, therefore, could cause considerable expense, associated with regenerating the GAC, when one of the less harmful organics exceeds 0.5 µg/l. Further, to our knowledge, the health effects of ingesting 0.5 µg/l of any of the volatile halogenated organic compounds has not been substantiated.

2. Removal of influent TOC with fresh GAC shall be at least 50%.

The selection of any percent removal criterion suggests that it is equally as safe to drink the water that contains 2,000 ug/l of TOC (50% of 4,000µg/l of TOC) as it is for one that contains 250 ug/l of TOC (50% of 500 µg/l of TOC). It further places a considerable significance on a "50%" level. For example, why not select 10%, 60%, 80%, or some other percentage? Therefore, the actual effluent concentration being ingested across the country would vary considerably due to the level of organics in raw water supplies, with the resulting health effect advantages unknown.

As indicated in the proposed rules, the use of TOC as a measurement tends to give excessive weight to naturally occurring, high molecular weight compounds which are not known to be hazardous. This being the case, more hazardous TOC constituents could exist in larger concentrations than acceptable, but be disguised in the TOC levels.

An advantage of this criterion and all TOC-based criteria is that the TOC analysis is relatively easy to run.

3. The effluent TOC may not exceed the value obtained with fresh GAC by more than 0.5 mg/l.

As in the case of 50% removal, this criterion has no health effects basis, allows considerable variability between the level of TOC in water consumed across the country, and could disguise higher levels of harmful organics. The further disadvantage is that it tends to unfairly condemn a GAC that is extremely effective when first placed in service. Under Objective 4, the use of bituminous and lignite GACs were evaluated and it was noted that, although the influents were common, the initial effluent concentrations of TOC in the two GACs were different. Therefore, by using this criterion, the GAC that was most effective when fresh might have to be removed for regeneration earlier and yet the effluent concentrations at the time of exhaustion would be lower than the other GAC whose initial effluent concentration was higher.

4. The effluent concentration shall not exceed 0.10 mg/l on an annual running average of THMSIMDIST effluent concentration.

This concentration is an existing MCL for distribution system samples and, therefore, would be an appropriate exhaustion criteria. Three-day THMSIMDIST serves as a surrogate for predicting the distribution system extremes for the CWW service area. One minor disadvantage is that it takes approximately four days to obtain results from this analysis. This criterion also ignores the hazard of other organics which are not detected under this analytical technique. The major advantages of this criterion are that it reflects an established MCL and further is representative of the quality of water being ingested.

5. The TOC concentration shall not consistently exceed 1.0 mg/l.

Although this criterion has the disadvantage that hazardous substances might be disguised by the non-harmful substances within TOC, at least there would be consistent year-round, city-to-city levels. Neither would the problems inherent in using percentages exist. Unfortunately there were no health effect relationships used to determine the 1.0 mg/l exhaustion criterion. Basically, it was developed because fresh GAC effluent TOC concentrations ranged from about 0.25 to 0.50 mg/l and when the recommended criterion[26] of 0.5 mg/l TOC is added, approximately 1.0 mg/l TOC results. Further, this is a reasonable level to achieve considering the raw water source.

6. The cumulative percent of TOC or THMSIMDIST loading shall not be less than 75%.

Under this criterion, the consumer will ingest water which contains, on an average, 75% fewer GAC-adsorbable organics. At exhaustion, the percent removal could be a much lower percentage than 75%, but the cumulative weight of organics retained, as a percent of the cumulative weight of contaminants contained in the influent, would never be less than 75% on a running average basis. An advantage is that a specific degree of removals could be selected and guaranteed to the consumer. The problem again with TOC or THMSIMDIST is that more harmful organics are not separately detectable by these two analytical techniques. Another disadvantage is that there are no health effect information substantiating the value of the 75% running average.

7. The slope of the TOC or THMSIMDIST percent removal graph tends to level off or plateau for at least three weekly samples. This condition, termed steady-state, would indicate exhaustion.

The primary disadvantage with this approach is that it is very difficult to detect a leveling off or at least where the leveling off occurs. The actual attainment of steady-state may not be discerned until the system is well past the point of exhaustion. Further, there is no health effects basis for this criterion. Also, steady-state could be reached at an unacceptable effluent concentration or percent removal level. The major advantage is that the most efficient use of the GAC would be assured.

8. The effluent TOC or THMSIMDIST concentration equals that of the influent (zero percent removal).

Keeping the GAC on line until this condition occurred would present unacceptable effluent concentrations even though the average purity of the water would be improved over sand filters alone. This approach would certainly give maximum life to the GAC since this condition did not occur in the bituminous GAC Systems studied.

Preferred Criteria--Based on the above considerations, the best criterion for exhaustion and, therefore, regeneration is likely when an established MCL is approached or when a three-week running average effluent concentration exceeds 1.0 mg/l TOC or 0.1 mg/l THMSIMDIST, whichever occurs first. The reasons are as follows:

1. These criteria combine fixed MCLs for a gross organic indicator (TOC) and for THMs. Therefore, a plant could be designed with minimum variability.

2. The 1.0 mg/l TOC concentration is approximately the level that would have resulted for CWW had the proposed GAC regulations[26] been adopted. This regulation called for criteria of 0.5 mg/l TOC above fresh GAC (which for CWW is about 0.75 to 0.8 mg/l) and 50% removal of influent TOC. At 1.0 mg/l TOC (about 50% of the average annual plant effluent TOC of 2.0 mg/l), both recommendations would be approximately met.

3. Although TOC could hide specific organic contaminants, CWW seldom saw any specific organics at quantities greater than 0.4 ug/l (lower detection limit of many EPA methods) during this study.

Tables 54 through 56 indicate the bed lives for GAC Filter 15A and Contactor D when the preferred exhaustion critera were used. In all cases the TOC criterion was more limiting than the THMSIMDIST criterion for GAC Filter 15A, the average bed life was 34 days, ranging from 22 to 57 days for the first three runs.

During Phase 3, attention was focused on maintaining, as nearly as possible, the original plan for a three-month regeneration cycle for Contactor D, the "control" contactor. As a result, only the longer virgin run of Contactor D reached the preferred exhaustion criterion at day 176. The two subsequent runs did not reach any of the criteria before being taken off line in runs of 106 and 126 days. A review of data from other Phase 3 contactors (9 runs) indicated that exhaustion was reached in eight of the runs for an average bed life of 93 days (range 50 to 148 days). Again, TOC was the exhaustion determinant.

Objective 10: Regenerated GAC Characteristics

To provide analytical data on regenerated GAC characteristics throughout the project CWW contracted with the Georgia Institute of Technology (GIT), Engineering Experimental Station. Analytical tests were conducted on selected samples of virgin, spent and regenerated GAC to determine the effectiveness of the regeneration process. Representative samples were taken from GAC Filter 23A (WVW 20 x 50), GAC Filter 15A (WVG 12 x 40), and Contactor D (WVG 12 x 40). These samples were dried, if necessary, at 100°C (212°F), mixed and reduced in size by the coning, quartering and riffling technique or by riffling alone. These samples were then sent to the GIT for GAC quality tests.

The GAC analyses data (Table 57) from GAC Filter 15A indicated that three of four regenerations proved successful and returned the GAC to the approximate original characteristics. The fourth regeneration did not return the GAC to the start-up qualities.

These data showed that three regenerations of GAC from Contactor D weresuccessful in returning the GAC to nearly original qualities. The data from GAC Filter 23A (WVW 20 x 50) indicated poor recovery which may have been dueto long exposure of this GAC and the fact that the regeneration system was calibrated for a different grain size GAC.

In-house GAC evaluations were also performed. Split GAC samples were evaluated by GIT and CWW. These comparison tests were: iodine number, sieve analysis (dry), apparent density and percent total ash. All of these test methods were identical to those used by GIT. As indicated in Table 58, a good correlation exists between the GIT and CWW results.

Objective 11. GAC Regeneration and Transport Losses

The bed-to-bed GAC losses included both regeneration and transport losses (Table 59). Losses for the contactors ranged from 9.8% to 18.9%; the average for nine regeneration cycles being 15.3%. GAC filter losses ranged from 13.6% to 23.7%, the average being 18.5% for six Phase 3 regeneration cycles. A detailed explanation of the technique used to obtain these figures is contained in Section 5.

The losses on GAC filters were greater than contactors due to the length and configuration of transport piping [maximum length 132.6 m (435 ft) including a number of short radius ells], the handling of the GAC with a shovel and the sandtable inefficiency. The contactor system, which was immediately adjacent to the regenerator, was specifially designed for minimum transfer losses with short runs and long radius ells.

Attempts were made to measure the regenerator battery losses dynamically from the spent GAC storage tank to the regenerated GAC storage tank. Grids were placed on top of the tanks and the contour of the GAC was measured at 30.5 cm (1 ft) increments using a leveling rod. An effort was made to complete the measurements of each tank within equal elapsed times. The

TABLE 57. GAC CHARACTERISTIC ANALYSES

GAC SYSTEM	GAC STATE	PHASE-RUN	IODINE NO.		SURFACE AREA (BET)		PHENOL WESTVACO		PHENOL AWWA-CALC.		MOLASSES NUMBER		MOISTURE		ASH		VOLATILE MATTER		APPARENT DENSITY, gm/ml	SCREEN ANALYSIS		PARTICLE DIAMETER, mm		ABRASION NO., %	
			mg/g	mg/ml	sq m/g	sq m/g	ppm	ml	mg/l	ulC/l	DIU	DIU/ml	%	gm/100ml	%	gm/100ml	%	gm/100ml		Eff. size, mm	UC	CALC.	GRAPH	MEAN	MEDIAN
15A	Virgin	3-0	1104	572.0	1101.7	532.1	16.2	33.5	1.86	3.81	10.50	5.07	1.48	0.72	7.06	3.41	2.49	1.20	0.483	0.73	1.74	1.251	1.190	67.3	72.3
15A	Spent	3-0	711	426.6	1051.4	602.5	38.3	63.8	4.36	7.27	5.90	3.54	1.35	0.81	19.10	11.46	11.00	6.60	0.600	0.75	1.91	1.336	1.340	73.6	76.8
15A	Regen.	3-0	1011	487.0	1022.4	492.8	21.7	45.0	2.47	5.12	10.80	5.21	0.42	0.20	8.31	4.00	3.87	1.86	0.482	0.69	1.70	1.178	1.080	69.5	76.9
15A	Startup[a]	3-1	1128	534.7	982.7	465.8	19.8	41.8	2.25	4.75	13.50	6.40	5.78	2.74	8.33	3.95	4.79	2.27	0.474	0.72	1.67	1.165	1.140	73.8	74.6
15A	Spent	3-1	1093	549.8	1129.9	533.3	32.4	64.4	3.69	7.34	11.20	5.63	2.31	1.16	10.48	5.27	10.66	5.36	0.503	0.52	1.92	0.932	0.900	68.4	70.0
15A	Regen.	3-1	1111	523.3	1118.5	526.8	21.1	45.0	2.41	5.12	14.50	6.83	1.38	0.65	8.44	3.98	5.38	2.53	0.471	0.61	1.72	0.945	0.970	69.8	72.2
15A	Startup[a]	3-2	1103	523.0	979.0	464.0	18.2	38.4	2.07	4.37	15.00	7.11	2.52	1.19	7.78	3.69	5.09	2.41	0.474	0.63	1.49	1.020	0.980	73.7	74.5
15A	Spent	3-2	916	447.0	1043.0	509.0	25.5	52.3	2.90	5.95	12.00	5.86	9.73	4.75	8.56	4.18	9.71	4.74	0.488	0.58	1.41	0.927	0.870	78.7	75.9
15A	Regen.	3-2	1083	504.0	1036.0	482.0	20.0	43.0	2.28	4.90	12.60	5.86	4.02	1.87	8.12	3.78	5.88	2.73	0.465	0.58	1.31	0.864	0.830	69.6	77.1
15A	Startup[a]	3-3	1104	510.0	1047.0	484.0	18.8	40.7	2.14	4.63	15.00	6.93	3.68	1.70	7.83	3.62	4.58	2.12	0.462	0.58	1.35	0.899	0.850	73.4	76.5
15A	Spent	3-3	896	472.0	936.0	493.0	28.8	47.1	2.82	5.36	9.56	5.04	18.60	9.80	8.63	4.55	7.63	4.02	0.527	0.73	1.44	1.130	1.130	79.4	80.5
15A	Regen.	3-3	986	512.0	880.0	457.0	18.9	36.4	2.15	4.15	11.30	5.86	11.70	6.07	7.45	3.87	4.45	2.31	0.519	0.66	1.36	1.023	0.970	79.7	81.4
23A	Virgin	1-0	903	516.5	818.9	468.4	17.6	30.8	2.00	3.50	7.60	4.35	4.55	3.60	8.59	4.91	3.22	1.84	0.572	0.40	1.47	.645	.560	71.8	85.2
23A	Spent	1-0	327	226.0	609.1	370.9	--	--	--	--	4.30	3.00	5.29	3.66	17.80	12.30	18.20	12.60	0.691	0.40	1.43	.558	.540	75.7	84.3
23A	Regen.	1-0	685	390.5	721.3	411.1	27.9	49.0	3.20	5.60	8.70	5.00	2.39	1.36	14.30	8.15	8.37	4.77	0.570	0.42	1.36	.563	.545	70.8	78.9
D	Virgin	3-0	1128	570.8	1069.5	541.2	18.0	35.6	2.05	4.05	9.60	4.86	2.29	1.16	8.10	4.10	3.57	1.81	0.506	0.64	1.80	1.100	1.070	76.5	78.5
D	Spent	3-0	824	459.8	1030.3	535.8	30.2	54.1	3.64	6.16	6.80	3.79	2.32	1.29	9.46	5.28	9.82	5.48	0.558	0.60	2.00	1.110	1.080	75.2	77.8
D	Regen.	3-0	1030	523.2	1045.5	531.1	20.3	40.0	2.31	4.55	10.70	5.44	1.00	0.51	8.96	4.55	4.85	2.46	0.508	0.58	1.90	1.040	1.000	72.1	74.0
D	Startup[a]	3-1	1096	547.0	948.0	473.0	17.0	34.1	1.94	3.88	11.00	5.49	1.59	0.79	7.66	3.82	3.38	1.69	0.499	0.62	1.49	1.063	1.000	80.4	85.0
D	Spent	3-1	880	461.0	936.0	490.0	24.2	46.2	2.76	5.26	8.30	4.35	6.79	3.56	7.67	4.02	8.10	4.24	0.524	0.68	1.52	1.131	1.120	78.9	79.5
D	Regen.	3-1	1096	543.0	1013.0	501.0	17.0	34.3	1.94	3.91	12.60	6.24	1.86	0.52	7.93	3.93	3.38	1.67	0.495	0.61	1.45	1.020	0.960	71.9	74.0

[a] Startup GAC consisted of the same proportions of regenerated GAC and virgin GAC makeup as were contained in full-scale system for next run.

TABLE 58. COMPARISON OF CWW AND GIT ANALYSES OF GAC CHARACTERISTICS

GAC System	GAC State	Phase-Run	Lab	Iodine No. mg/gm	App. Density gm/ml	Total Ash %	Sieve Analysis Eff. Size mm	Sieve Analysis Unif. Coef.
15A	Virgin	3-0	CWW	1181	0.47	6.0	0.78	1.56
			GIT	1184	0.48	7.1	0.73	1.74
15A	Spent	3-0	CWW	805	0.58	27.6	0.90	1.62
			GIT	711	0.60	19.1	0.75	1.91
15A	Regenerated	3-0	CWW	1021	0.48	7.6	0.70	1.63
			GIT	1011	0.48	8.3	0.69	1.70
15A	Startup[a]	3-1	CWW	1084	0.49	8.4	0.83	1.50
			GIT	1128	0.47	8.3	0.72	1.67
15A	Spent	3-1	CWW	902	0.51	10.9	0.62	1.60
			GIT	1093	0.50	10.5	0.52	1.92
15A	Regenerated	3-1	CWW	1061	0.47	8.7	0.60	1.67
			GIT	1111	0.47	8.4	0.61	1.72
15A	Startup	3-2	CWW	1093	0.49	8.1	b	b
			GIT	1103	0.47	7.8	0.63	1.44
15A	Spent	3-2	CWW	914	0.53	10.2	0.62	1.51
			GIT	916	0.49	8.6	0.58	1.41
15A	Regenerated	3-2	CWW	1060	0.48	8.8	0.62	1.45
			GIT	1083	0.47	8.1	0.58	1.31
15A	Startup	3-3	CWW	1067	0.48	9.1	0.62	1.48
			GIT	1104	0.46	7.8	0.58	1.35
15A	Spent	3-3	CWW	881	0.62	9.1	0.71	1.60
			GIT	896	0.53	8.6	0.73	1.44
15A	Regenerated	3-3	CWW	923	0.60	8.2	b	b
			GIT	986	0.52	7.5	0.66	1.36
23A	Virgin	1-0	CWW	858	0.59	8.1	0.42	1.45
			GIT	903	0.57	8.6	0.40	1.47
23A	Spent	1-0	CWW	325	0.72	36.0	0.38	1.53
			GIT	327	0.69	17.8	0.40	1.43
23A	Regenerated	1-0	CWW	669	0.58	15.2	0.40	1.45
			GIT	721	0.57	14.2	0.42	1.36
D	Virgin	3-0	CWW	1077	0.51	8.2	0.68	1.82
			GIT	1128	0.51	8.1	0.64	1.80
D	Spent	3-0	CWW	885	0.55	10.6	0.76	1.60
			GIT	824	0.58	9.5	0.60	2.00
D	Regenerated	3-0	CWW	1008	0.49	9.6	0.70	1.68
			GIT	1030	0.51	9.0	0.58	1.90
D	Startup	3-1	CWW	1064	0.49	8.1	0.62	1.74
			GIT	1096	0.50	7.7	0.62	1.49
D	Spent	3-1	CWW	849	0.55	8.1	0.84	1.67
			GIT	880	0.52	7.7	0.68	1.52
D	Regenerated	3-1	CWW	1075	0.50	8.1	0.62	1.71
			GIT	1097	0.50	7.9	0.61	1.45

[a] Start-up GAC consisted of the same proportions of regenerated GAC and virgin GAC makeup as were contained in full-scale for next run.

[b] Not run.

TABLE 59. TOTAL GAC LOSSES[a]

Contactor			GAC Filter		
Location	Phase	Percent Loss	Location	Phase	Percent Loss
C	3-0	15.8	15A	3-0	22.6
D	3-0	14.9	21A	3-1	22.6
A	3-0	13.8	15A	3-1	23.7
BB	3-0	18.0	21A	3-2	13.7
C	3-1	15.6	15A	3-2	13.6
D	3-1	18.9	15A	3-3	14.8
A	3-1	14.2			
D	3-2	16.4			
BB	3-1	9.8			
Average Loss, %		15.3	Average Loss, %		18.5

[a] Total losses calculated by volume measurements in each GAC adsorption bed.

volume of GAC was determined according to the "borrow-pit" method. The losses determined by this method (Table 60) were inconsistent and not reflective of bed-to-bed losses. These losses, therefore, were considered invalid due to the following shortcomings in the process: small sample size, variances in elapsed time of measuring each tank, erratic furnace operations

TABLE 60. GAC LOSSES ACROSS FURNACE[a]

Contactor			GAC Filter		
Location	Phase	Percent Loss	Location	Phase	Percent Loss
D	3-0	15.9	21A	3-1	31.2
A	3-0	12.0	15A	3-1	16.4
BB	3-0	14.6	21A	3-2	16.6
C	3-1	16.7	15A	3-2	8.7
D	3-1	3.4			
A	3-1	22.8			
D	3-2	27.9			
Average Loss, %		16.2	Average Loss, %		18.2

[a] Furnace losses calculated by volume measurements in spent and regenerated GAC tanks.

during tests and the difficulty associated with measuring an irregular surface obscured by many feet of carbon-black water.

Three transport and regenerator battery loss tests were conducted on the contactors (Table 61) to assess performance under the regenerator construction contract guarantees. The average transport loss of 3.1% was greater than anticipated, based on current literature, although it is comparable to losses reported from other GAC facilities. The regeneratory battery losses fluctuated considerably from 12% to 7% to 14% in three tests. The average 11% loss was much greater than that predicted by furnace manufacturers.

On several occasions, attempts were made to determine the efficiency of the sand separator during GAC filter runs. Percent sand-in-GAC analyses were run during GAC furnace loss tests, transport loss tests, and at other times during runs. Samples were collected from the sand and GAC discharge ends of the sand separator. The results contained in Table 62 indicate that the sand separator, although removing most of the sand, did not completely prevent sand from entering the furnace. As described in Objective 12, sand which entered the furnace hampered furnace operations.

TABLE 61. CONTACTOR GAC TRANSPORT LOSSES

Contactor	Phase-Run	Transport Loss, %	Regenerator Battery Loss, %	Bed to Bed Loss, %
C	3-1	4.0	11.6	15.6
BB	3-2	3.0	6.8	9.8
D	3-2	2.4	14.0	16.4
Average Loss, %		3.1	10.8	13.9

TABLE 62. SAND SEPARATOR, PERCENT SAND IN GAC

Sample Date	Sand Separator Sample Location	GAC Filter	Percent Sand by Volume	Percent GAC by Volume
Sep. 26, 1980	Sand Discharge	21A	84.6	15.4
Feb. 20, 1981	Sand Discharge	15A	69.1	30.9
Mar. 25, 1981	GAC Discharge	15A	4.6	95.4
June 1, 1981 (1st shift)	Sand Discharge	21A	81.5	18.5
June 1, 1981 (2nd shift)	GAC Discharge	21A	1.5	98.5
June 1, 1981 (3rd shift)	GAC Discharge	21A	0.0	100.0
June 2, 1981 (1st shift)	GAC Discharge	21A	5.2	94.8
June 2, 1981 (2nd shift)	GAC Discharge	21A	0.0	100.0
June 2, 1981 (3rd shift)	GAC Discharge	21A	2.5	97.5
-	Sand Discharge	Avg.	78.4	21.6
-	GAC Discharge	Avg.	2.3	97.7

More important to the consideration of GAC losses is that an average of 22% (by weight) of the discharge from the sand end of the separator was GAC. This is not as significant as it may seem since the total volume of discharge off of the sand end of the separator averaged less than 3% of the total volume of materials regenerated in any one run. Therefore, the GAC losses from the sand end of the separator were less than 1% of the volume of materials regenerated. Further, it should be noted that the sample collection process (core sampling or grab sampling) may have introduced considerable error and, since separator adjustments were made continually throughout a run, the results obtained may not be representative of that total run.

Objective 12. To Develop Parameters to be Used in the Design of Full-Scale Systems

Sand Replacement GAC Filters--

Design criteria--

Empty bed contact time--Probably the most significant parameter in designing a GAC system, EBCT, is somewhat fixed for sand replacement GAC filters. Most existing rapid sand filters are designed for 1.4 to 2.8 lps/sq m (2 to 4 gpm/sq ft) and bed depths of 61 to 76.2 cm (24 to 30 in). Conversion of these facilities for GAC use results in EBCTs of 3.7 to 9.4 minutes. Existing sand filters at CWW are designed for 1.7 lps/sq m (2.5 gpm/sq ft) and contain 76.2 cm (30 in) of media, resulting in an EBCT of 7.5 minutes. Comparisons between filters with 30.5 cm (12 in) of filter sand and 45.7 cm (18 in) of GAC and filters with 76.2 cm (30 in) of GAC have established that the sand layer is unnecessary from the standpoint of filtration (Objective 2). Elimination of the sand layer results in a 40% increase in EBCT.

Within the range of EBCTs available in converted sand filters, bed service life, carbon use rate, and regeneration requirements are all improved as the EBCT increases. Optimization of available EBCT should, therefore, be evaluated when filters are converted from sand to GAC.

Surface loading--Full-scale performance at CWW indicated that WVG 12 x 40 GAC functioned satisfactorily at a surface loading of 1.7 lps/sq m (2.5 gpm/sq ft). Turbidity reduction was equivalent to that of sand filters operated in parallel with GAC filters (Objective 2).

Carbon use rate and carbon service life are functions of EBCT, the criteria selected to indicate GAC exhaustion, and the concentration of contaminants in the influent to the GAC filters. Seasonal variations in the concentrations of certain organic parameters must also be considered in design. Plots of TOC and THMSIMDIST in the raw water, sand filter influent and sand filter effluent indicate seasonal trends due to temperature, runoff, etc. (Figures 110 and 111).

Full-scale adsorption systems must be designed for the shortest, or critical, expected bed service life and maximum water production during the

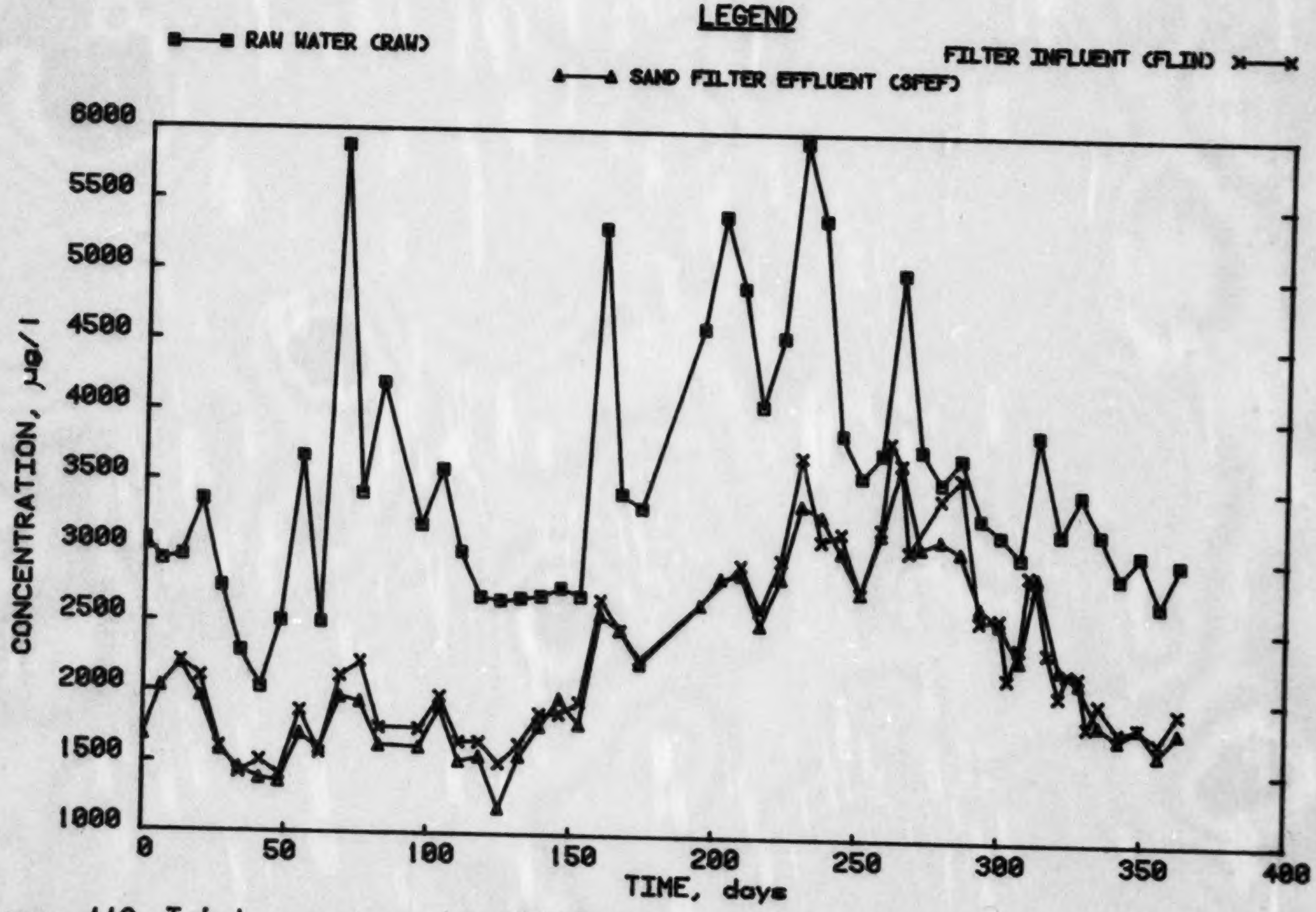


Figure 110. Total organic carbon (TOC) in raw, filter influent and sand filter effluent locations for the year 1980.

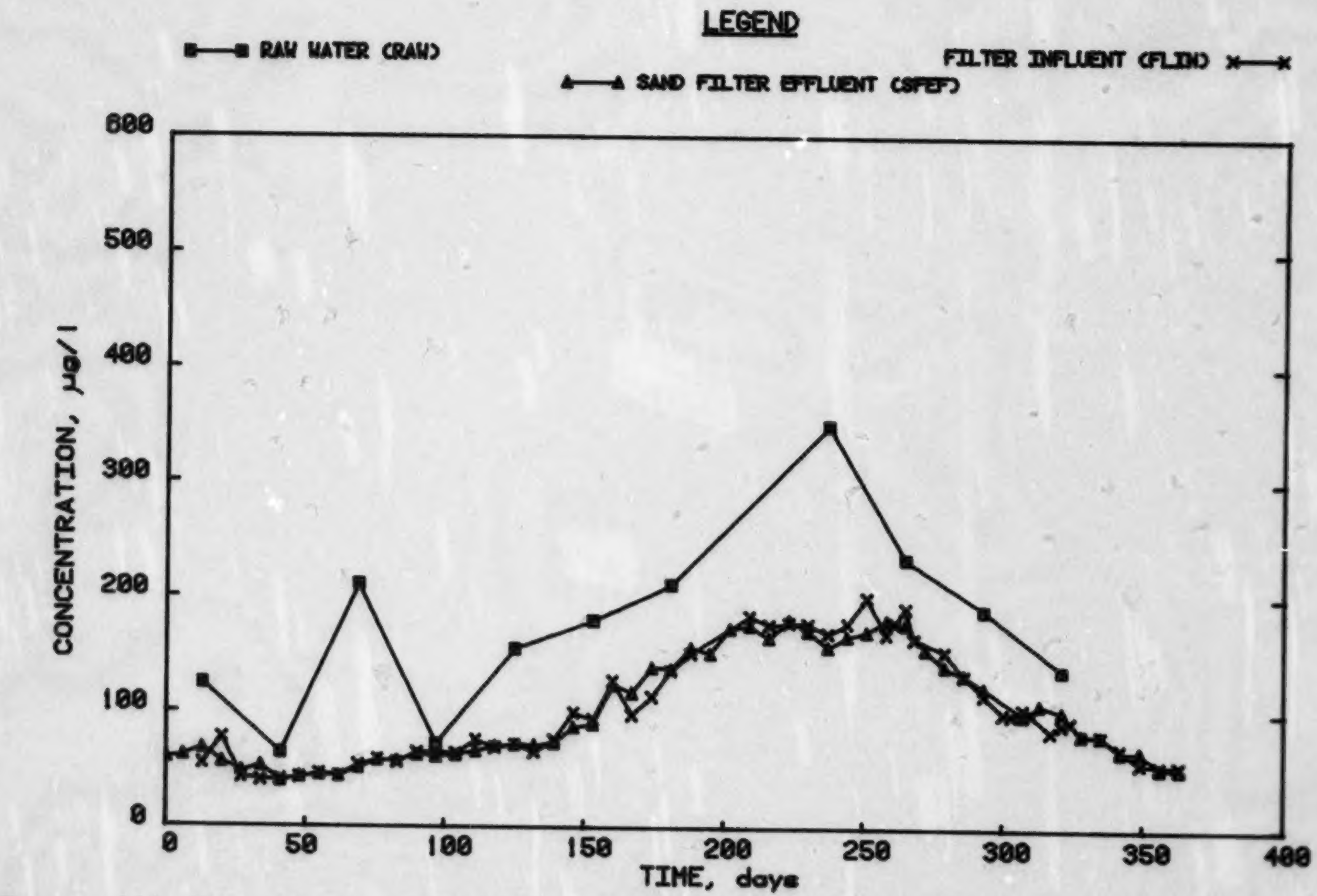


Figure 111. Three-day simulated distribution system THM (STT3) in raw, filter influent and sand filter effluent locations for the year 1980.

summer months. Operating costs, especially those for GAC consumption, will be reflective of longer service life and reduced water production during winter months.

Figure 112 and Tables 63 and 64 present seasonal TOC and THMSIMDIST concentration data for GAC filters. "Summer critical" curves reflect the shortest service life to achieve a given effluent goal, based on four summer runs. "Winter average" curves present the average service life to achieve a given effluent goal, based on four winter runs and is presented to emphasize the critical nature of summer data.

These exhaustion criteria (e.g. 1,000 µg/l TOC) should not be applied to any single GAC filter, but rather to total plant effluent. Actual plant operation will include multiple GAC filters operating at the same time in parallel. Individual GAC filters will be placed into and taken out of service for GAC replacement on a "staggered schedule".

To meet a desired treatment goal in the combined flow from all filters, some units may produce an effluent exceeding the treatment goal as long as other units produce water equally below the treatment goal. Due to the fact that the quality of the total plant output would be the average of the quality of all filters in service, it follows that the bed life of each filter would be approximately twice that of an individual filter operating toward the same exhaustion goal.

For example, from Figure 112's TOC summer critical line, if 1,000 µg/l TOC were the plant average treatment goal, then a combined effluent from a fresh GAC filter passing about 500 µg/l TOC would permit an older GAC filter to pass 1,500 µg/l TOC. The figure shows that it took 18 days to reach the 1,500 µg/l treatment goal. Had the GAC filter been taken off line at a goal of 1,000 µg/l TOC, the service life would have been 8 days. Therefore, the average life of a single filter would be approximately twice those indicated in Tables 63 and 64. Since carbon use rate is inversely proportional to service life, carbon use rates applicable to staggered operation would be one-half those of any single filter.

Therefore, carbon use rates and service life data are useful in the design of GAC application and regeneration facilities and in the projection of costs for building and operating them. It should be noted that TOC was always the determinant of exhaustion rather than THMSIMDIST.

The "summer critical" carbon use rate is an important factor for design, since facilities must be sized to handle this critical period. Thus for 1,000 µg/l TOC the carbon use rate of 160 kg/mil l (1,334 lb/mil gal) (calculated from Table 63's summer critical service life) and the service life of 16 days (2 times the Table 63 summer critical value) were used.

Due to significant variability in the influent concentration of contaminants, the annual average carbon use rate was used for determining operating and maintenance factors and costs. Thus for 1,000 µg/l TOC, the carbon use

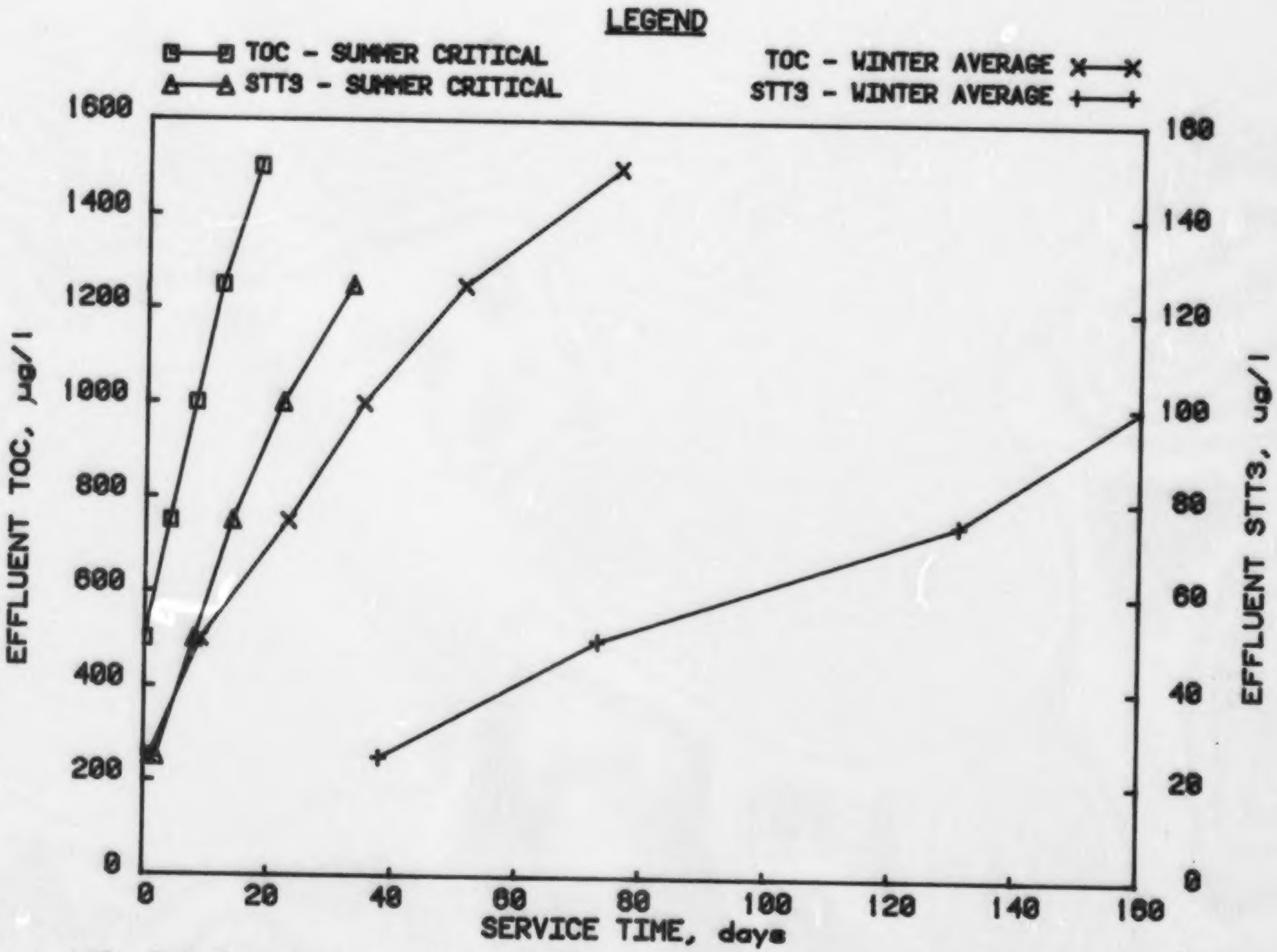


Figure 112. Total organic carbon (TOC) and three-day simulated distribution system THM (STT3) seasonal service time curves for GAC filters.

TABLE 63. GAC FILTER SERVICE LIVES FOR SELECTED TOC TREATMENT GOALS, IN DAYS

GAC Filter	Phase-Run	Start Month	Treatment Goals, µg/l					
			250	500	750	1,000	1,250	1,500
Summer								
15A	3-1	Aug. '80	0	0	4	9	14	20
15A	3-2	Oct. '80	0	2	7	11	16	42
21A	3-1	Jul. '80	0	1	4	8	12	18
21A	3-2	Oct. '80	0	2	7	12	21	30
Summer Critical			0	0	4	8	12	18
Winter								
15A	3-0	Jan. '80	0	8	32	47	55	115
15A	3-3	Dec. '80	3	11	23	32	42	48
15A	3-4	Mar. '81	0	16	26	42	48	50
21A	3-3	Feb. '81	0	0	10	19	60	90
Winter Average			1	9	23	35	51	76

TABLE 64. GAC FILTER SERVICE LIVES FOR SELECTED THMSIMDIST TREATMENT GOALS, IN DAYS

GAC Filter	Phase-Run	Start Month	Treatment Goals, µg/l				
			25	50	75	100	125
Summer							
15A	3-1	Aug. '80	4	10	17	24	34
15A	3-2	Oct. '80	10	42	-	-	-
21A	3-1	Jul. '80	2	8	14	22	33
21A	3-2	Oct. '80	7	21	-	-	-
Summer Critical			2	8	14	22	33
Winter							
15A	3-0	Jan. '80	52	103	131	160	-
15A	3-3	Dec. '80	-	-	-	-	-
15A	3-4	Mar. '81	35	55	-	-	-
21A	3-3	Feb. '81	36	60	-	-	-
Winter Average			38	73	131	160	-

rate of 96 kg/mil l (800 lb/mil gal) (one half of Figure 113 value) and the service life of 38 days (two times Figure 114 value) were used.

Backwash requirements--A study was conducted to determine the appropriate backwash rate for the GAC filters. A rate of 5.6 lps/sq m (8 gpm/sq ft) was found to expand the GAC bed without washing GAC out of the filter. Backwashing was accomplished at a rate of 2 lps/sq m (3 gpm/sq ft) for 4 minutes, 4.1 lps/sq m (6 gpm/sq ft) for 4 minutes and then 5.4 lps/sq m (8 gpm/sq ft) for 4 minutes. GAC filters exhibited average service times, between backwashings, which were approximately 50% longer than conventional sand filters (Objective 2).

Regeneration requirements--GAC regeneration requirements are dictated by summer operation. Raw water TOC, THMSIMDIST and water consumption are all maximum during this period. This results in minimum GAC filter service life and maximum required filtration capacity at the same time. Regeneration capacity must, therefore, be sufficient to handle the spent GAC generated daily at the maximum monthly average flow and the carbon use rate resulting from the critical summer service life.

Standby GAC filter capacity--Removal and replacement of GAC requires taking GAC filters out of service for a period of time for each regeneration cycle. During this study, spent GAC was manually shovelled to an eductor box. Regenerated GAC was returned to the filters as a slurry delivered by a large diameter hose. The GAC bed was then backwashed and allowed to settle. Additional GAC was added and this procedure repeated until the desired bed depth was achieved. This process required approximately five days per filter.

Full-scale GAC filters will require improved methods of spent GAC removal. Alternate methods of GAC removal are site-specific and beyond the scope of this study. It seems reasonable, however, to assume that GAC filter downtime for removal and replacement of spent GAC can be reduced to two days per regeneration cycle. To maintain equal plant capacity after conversion from sand filters to GAC filters, additional filters must be constructed to compensate for those out of service for GAC replacement. The required standby GAC filter capacity is the maximum capacity which would become exhausted daily multiplied by the expected duration of downtime to remove and replace the spent GAC. The maximum capacity to be exhausted daily is that resulting from maximum monthly average water production and critical summer service life. As indicated in Objective 13, an additional six filters would be required at an exhaustion criterion of 1,000 μg/l TOC.

Design consideration--

GAC handling and transport--During this study, spent GAC was removed by shovelling to an eductor box. This labor intensive removal method is impractical for full-scale facilities. Other methods should be evaluated prior to design. This evaluation should consider minimizing the quantity of transport water required as well as reducing operating labor.

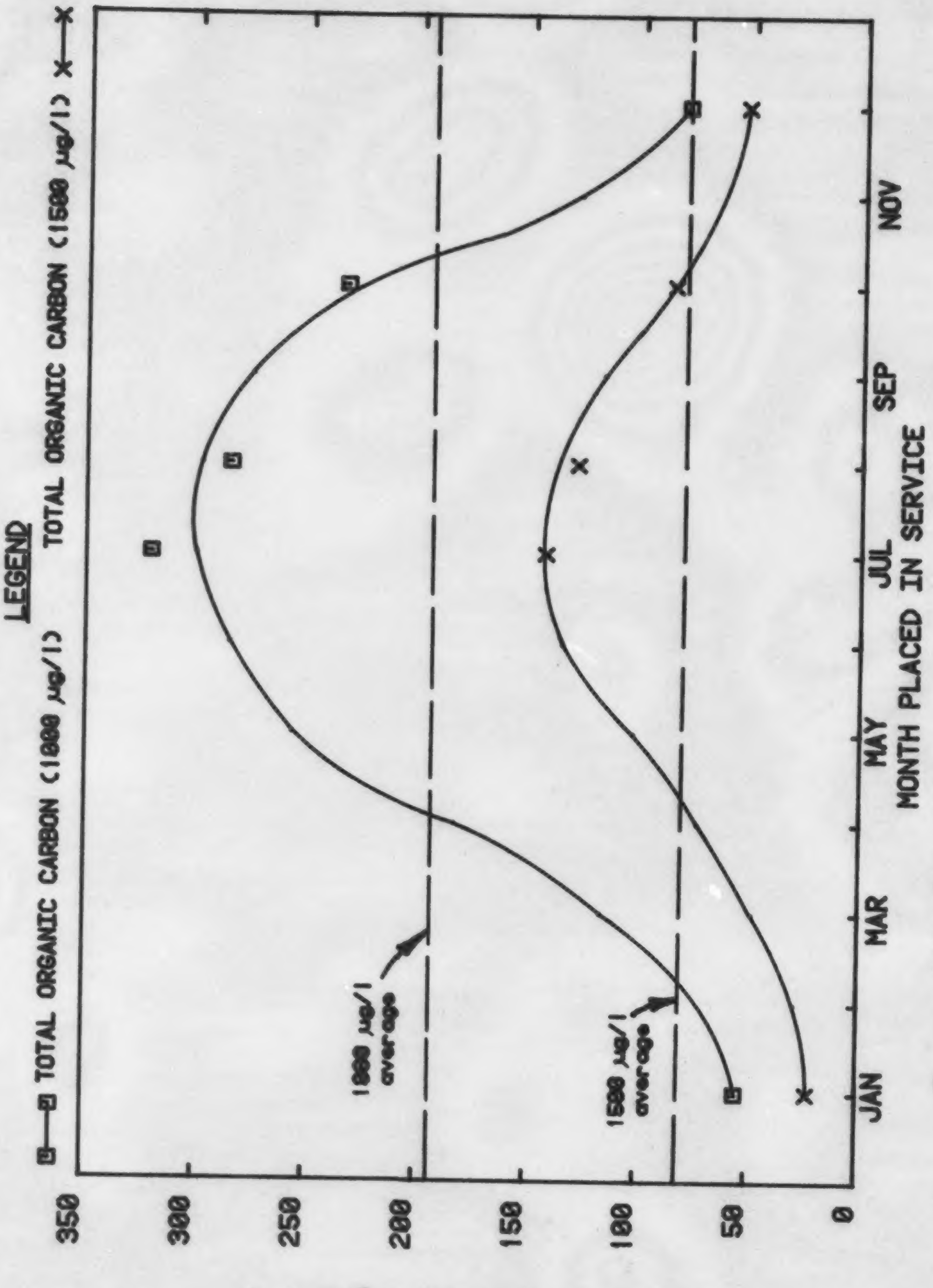


Figure 113. GAC filter carbon use rates, 1980.

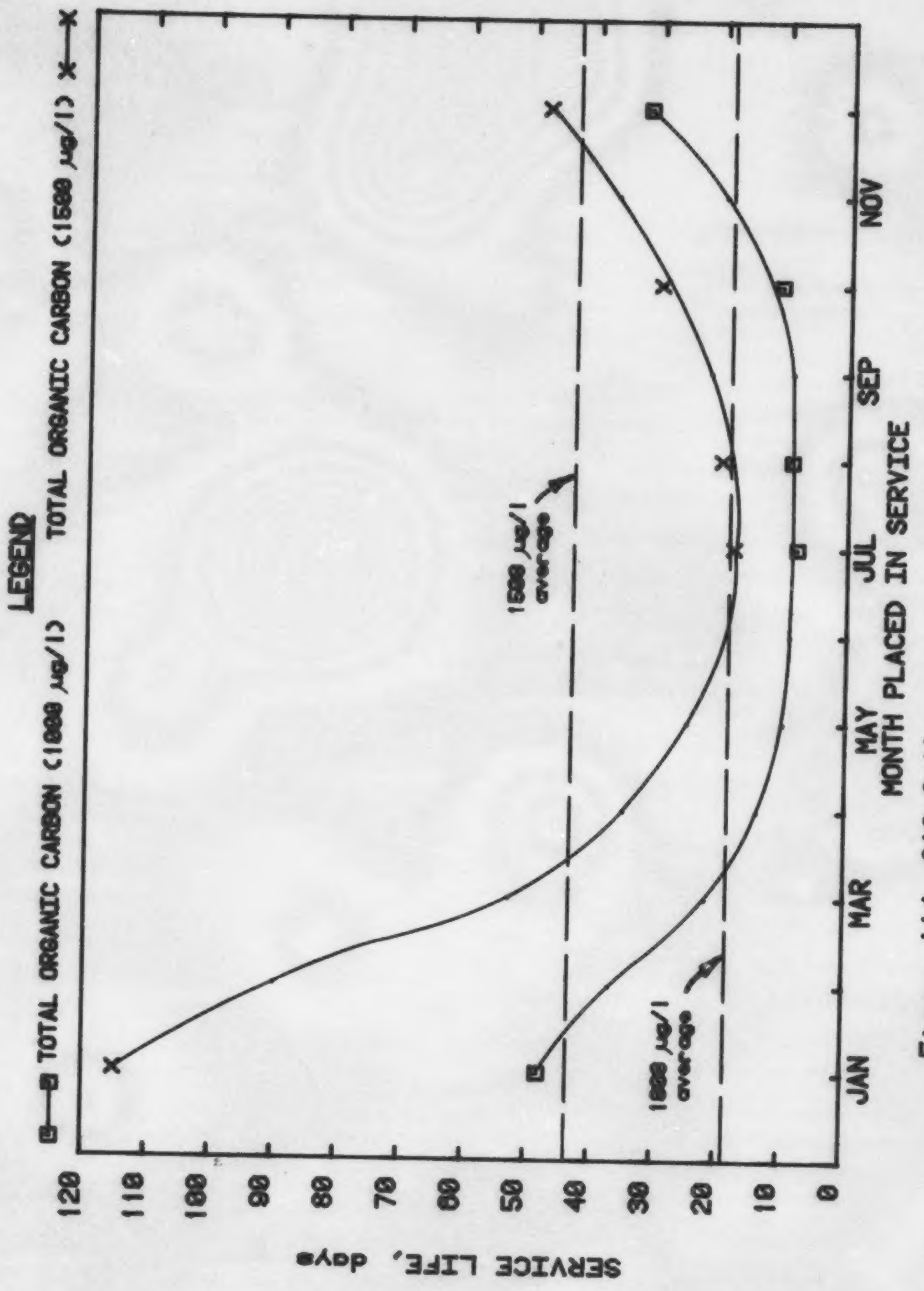


Figure 114. GAC filter service lives, 1980.

Less labor-intensive methods of GAC replacement should also receive careful evaluation. A permanent installation of transport piping to each GAC filter should be considered. As a minimum, consideration should be given to an overhead crane for moving GAC handling equipment between filters.

GAC transport piping used in this study was black steel pipe with forged steel fittings. Although proven to be satisfactory, other more economical pipe materials should be evaluated. Special consideration must be given to pipe sizing, bend radii and slurry consistency to minimize abrasion and velocity to maintain suspension.

Related plant modifications--Several plant modifications are required in support of filter conversion for GAC treatment. Additional filter capacity will likely be required to compensate for filters down for GAC removal and replacement. Washwater storage and pumping facilities may need to be expanded to meet backwash and GAC transport requirements.

When converting sand filters, consideration should be given to optimizing the available EBCT. Methods of supporting the GAC bed, which will prevent intermixing of GAC and sand, should be evaluated.

GAC treatment removes all free chlorine from the water resulting in bacterial growth. Post-chlorination facilities will be required for any GAC treatment system. Additional facilities may be required to ensure sufficient chlorine contact time prior to distribution.

Post-filtration GAC Contactors

Design criteria--

Empty bed contact time--Figure 115 contains plots of carbon use rate versus optimum EBCT for each contactor run during the study period. Carbon use rates were calculated as the weight of GAC required per volume of water throughput until the treatment goal of 1,000 µg/l TOC was reached based on a three-week running average. (Each three-week set along the curve was averaged and a new curve plotted from these values. The point at which this curve intersected the treatment goal became the point of exhaustion.) As shown by the average of all contactor runs, carbon utilization efficiency improved (carbon use rate decreased) substantially as EBCT was increased to 15 minutes. Optimum carbon utilization apparently occurred at an EBCT greater than 15 minutes, possibly 20 minutes, for the critical late summer months. Determining which of the two EBCTs is the most cost-effective, however, requires a look at the costs and benefits of increasing EBCT (Objective 13).

Surface loading--Pressure contactors utilized during this study operated at a surface loading of 5 lps/sq m (7.4 gpm/sq ft). No significant reduction in pressure was noted during contactor runs probably because the water had previously been filtered. Therefore, backwashing was not required to maintain a constant rate. Since filtration is not a factor in contactor design,

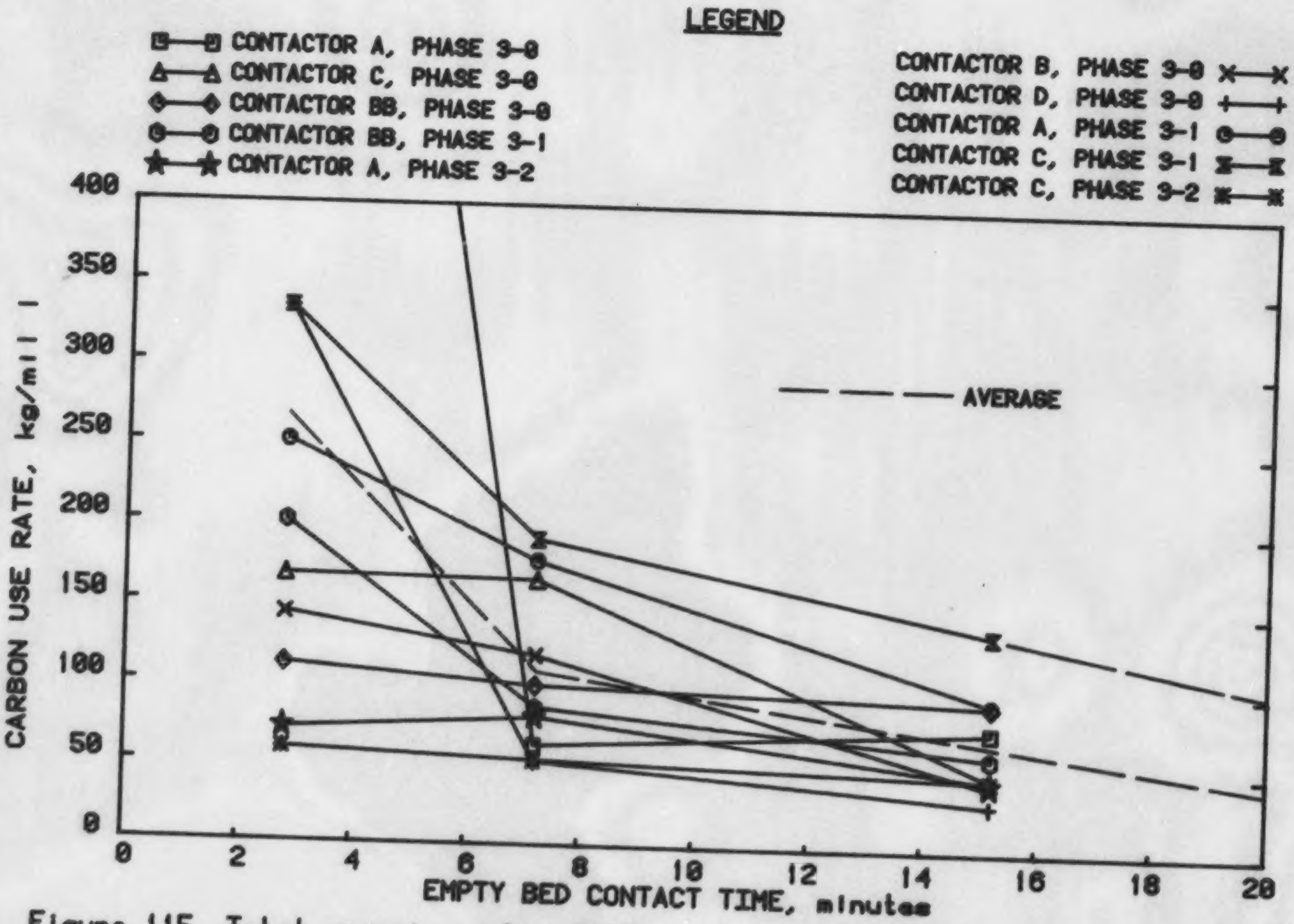


Figure 115. Total organic carbon (TOC) carbon use rates for multiple runs of contactors, Phase 3 (TOC=1000 μg/l).

surface loading is a function of allowable head loss and space availability. Surface loadings commonly range from 3.4 to 6.8 lps/sq m (5 to 10 gpm/sq ft). High liquid velocities resulting from surface loadings greater than 6.8 lps/sq m (10 gpm/sq ft) may inhibit mass transfer and reduce adsorption in the contractor.

Carbon use rate--as previously mentioned under GAC filters, carbon use rate and service life are functions of EBCT, the criteria selected to indicate GAC exhaustion, and the concentration of contaminants in the influent to the contactors. Therefore, the considerable variations in influent concentrations must be also considered in the design of contactors.

Table 65 and Figures 116 and 117 present the results of these variations for TOC and THMSIMDIST concentrations for the contactors. Figure 118 illustrates significant variations in carbon use rates for a treatment goal of 1,000 µg/l TOC and 15 minute EBCT. As can be noted therein, "summer critical" and "staggered scheduling" phenomena, as observed for GAC filters, also exist relative to the contactors, except that carbon use rates and service lives are considerably improved. Therefore, carbon use rates and service life data are useful in the design of carbon application and regeneration facilities and in the projection of costs for building and operating them.

The "summer critical" carbon use rate is an important factor for design, since facilities must be sized to handle this critical period. Thus for 1,000 µg/l TOC and a 15 minute EBCT, the carbon use rate of 68 kg/mil l (562 lb/mil gal) (one-half of the Figure 115 critical C (3-1) value) and the service life of 78 days (two times the Figure 116 summer critical value) were used.

Due to significant variability in the influent concentration of contaminants, the annual average carbon use rate was used for determining operating and maintenance costs. Thus for 1,000 µg/l TOC and a 15 minute EBCT, a carbon use rate of 34 kg/mil l (285 lb/mil gal) (one-half of the Figure 118 average annual carbon use rate) and a service life of 186 days (two times Figure 119's value) were used.

Although data were not collected at a 20-minute EBCT, service life may

TABLE 65. CONTACTOR SERVICE LIFE, IN DAYS

Parameter	Treatment Goal ug/l	Season	EBCT 2.8 min	EBCT 7.2 min	EBCT 15.2 min
THMSIMDIST	100	Summer (Critical)	9	23	70
THMSIMDIST	25	Summer (Critical)	2	9	29
TOC	1,000	Summer (Critical)	3	13	39
TOC	1,000	Winter (Average)	13	37	133

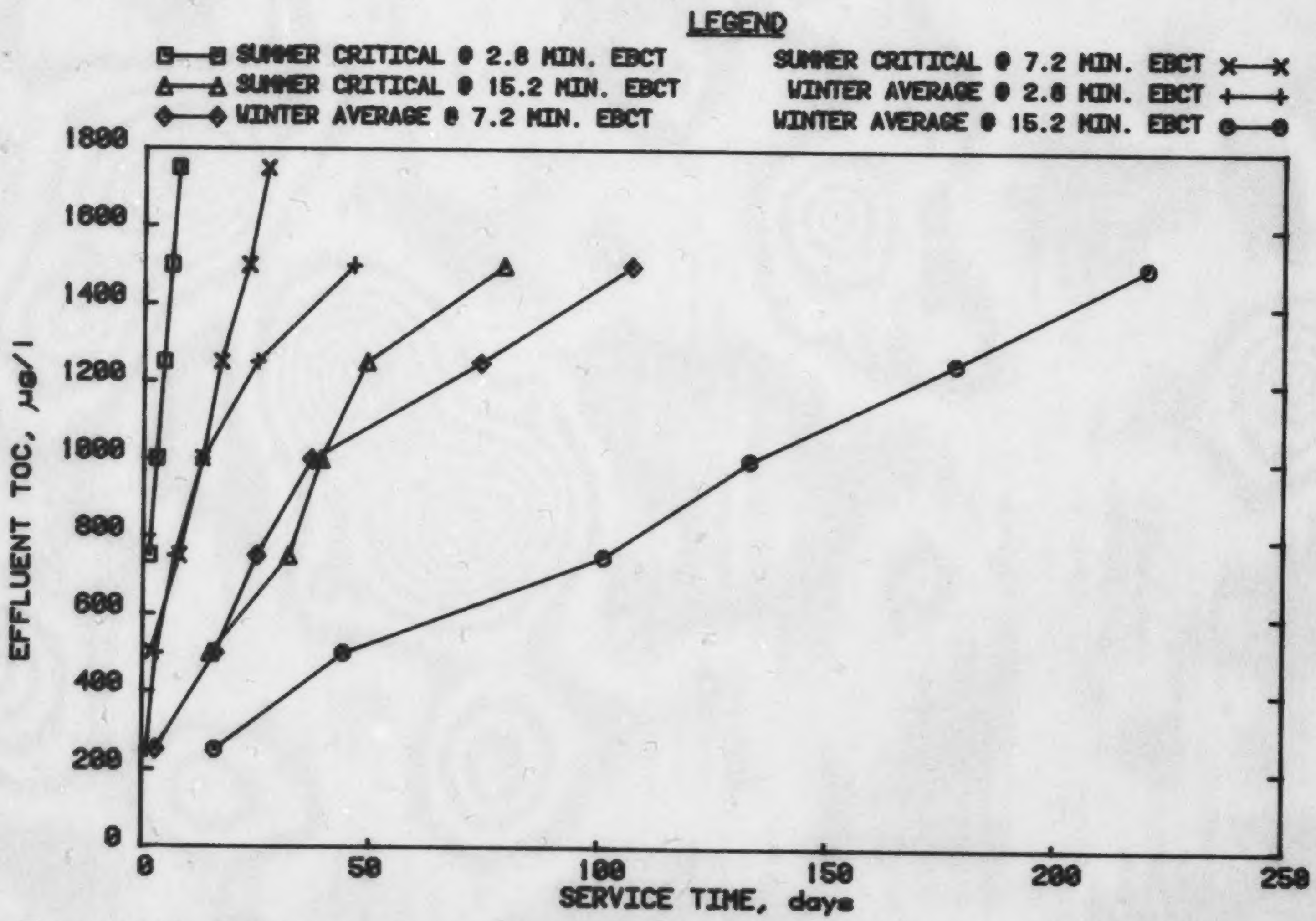


Figure 116. Total organic carbon (TOC) seasonal service time curves for contactors, Phase 3.

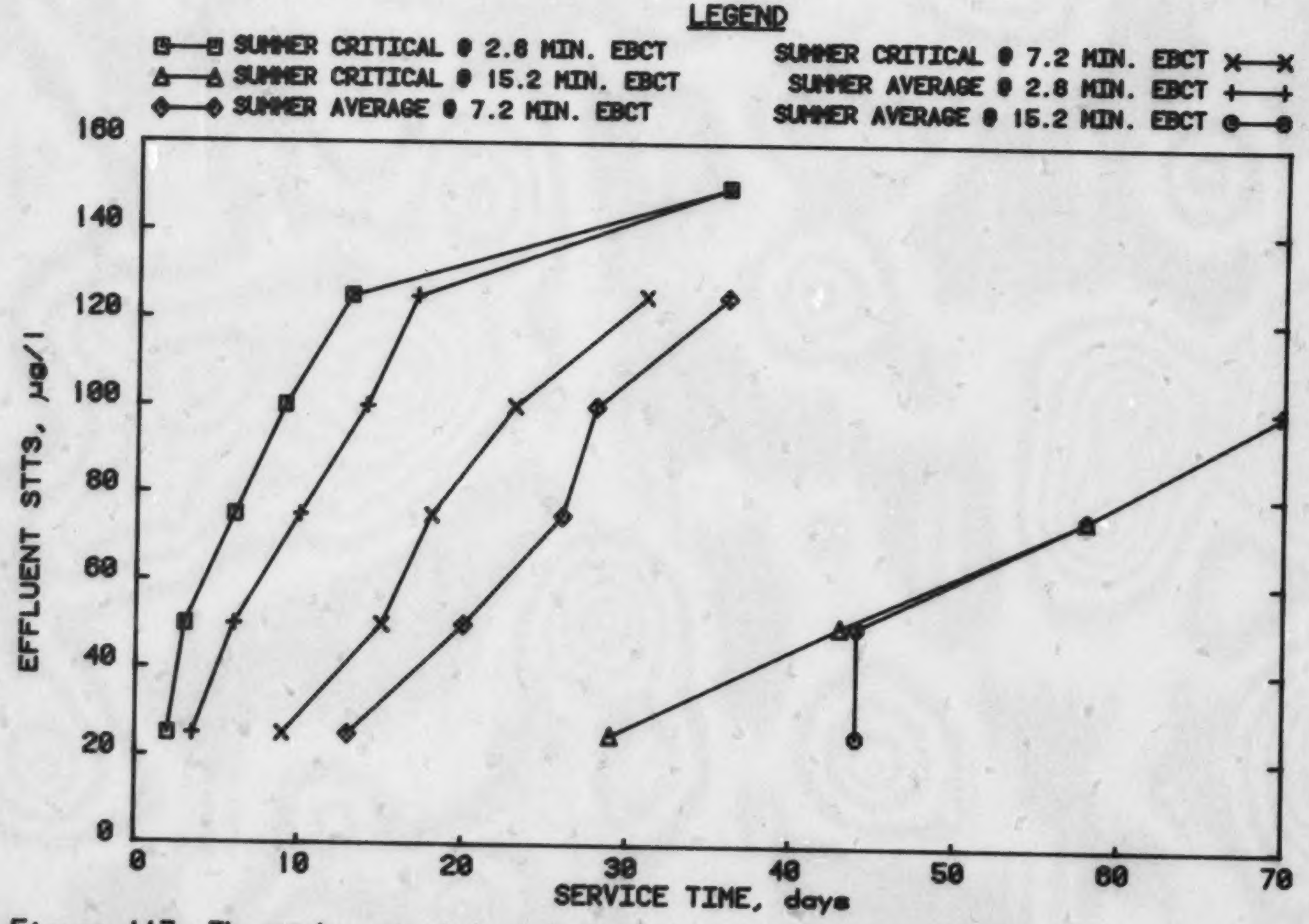


Figure 117. Three-day simulated distribution system THM (STT3) seasonal service time curves for contactors, Phase 3.

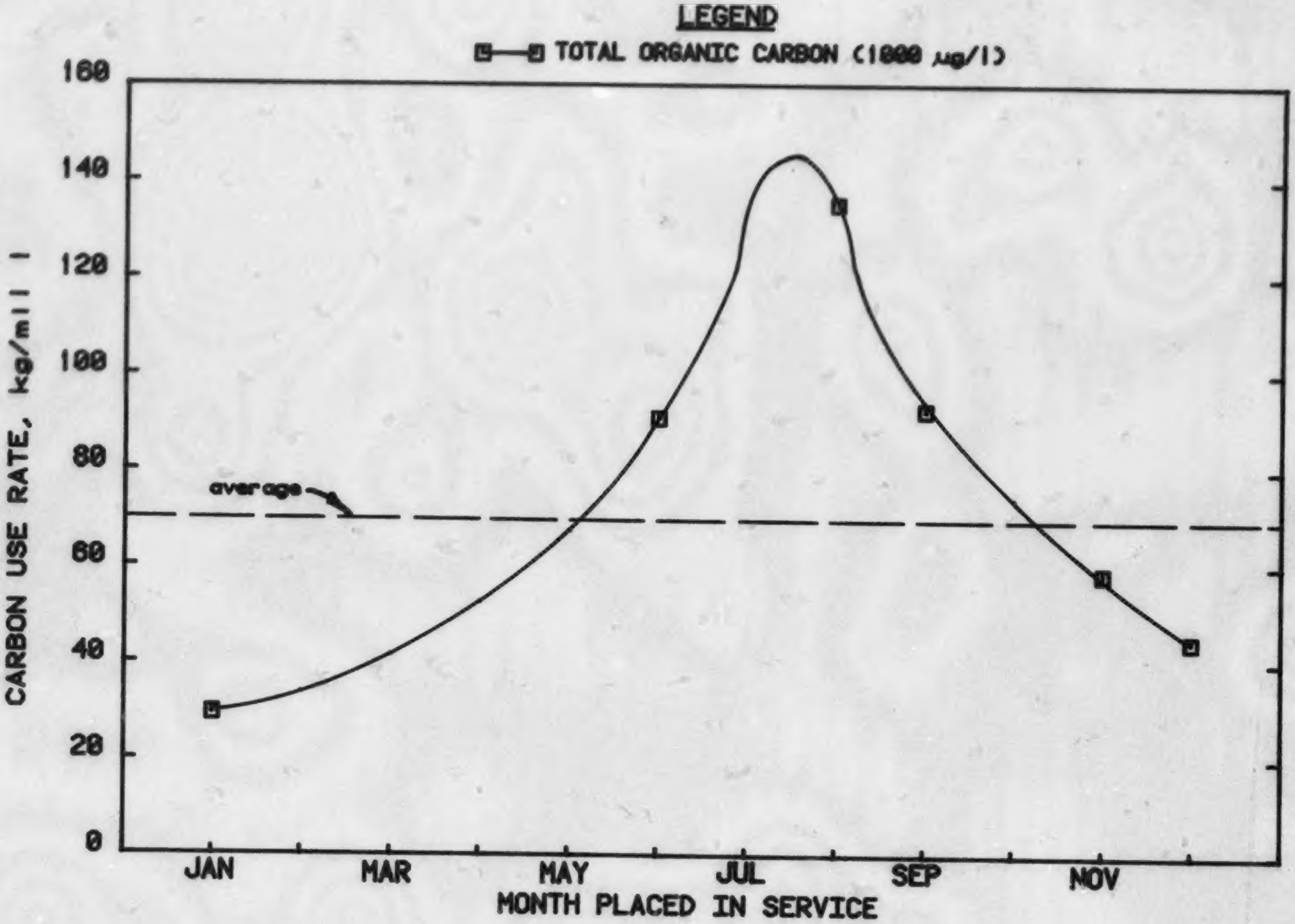


Figure 118. Contactor carbon use rate, 1980.

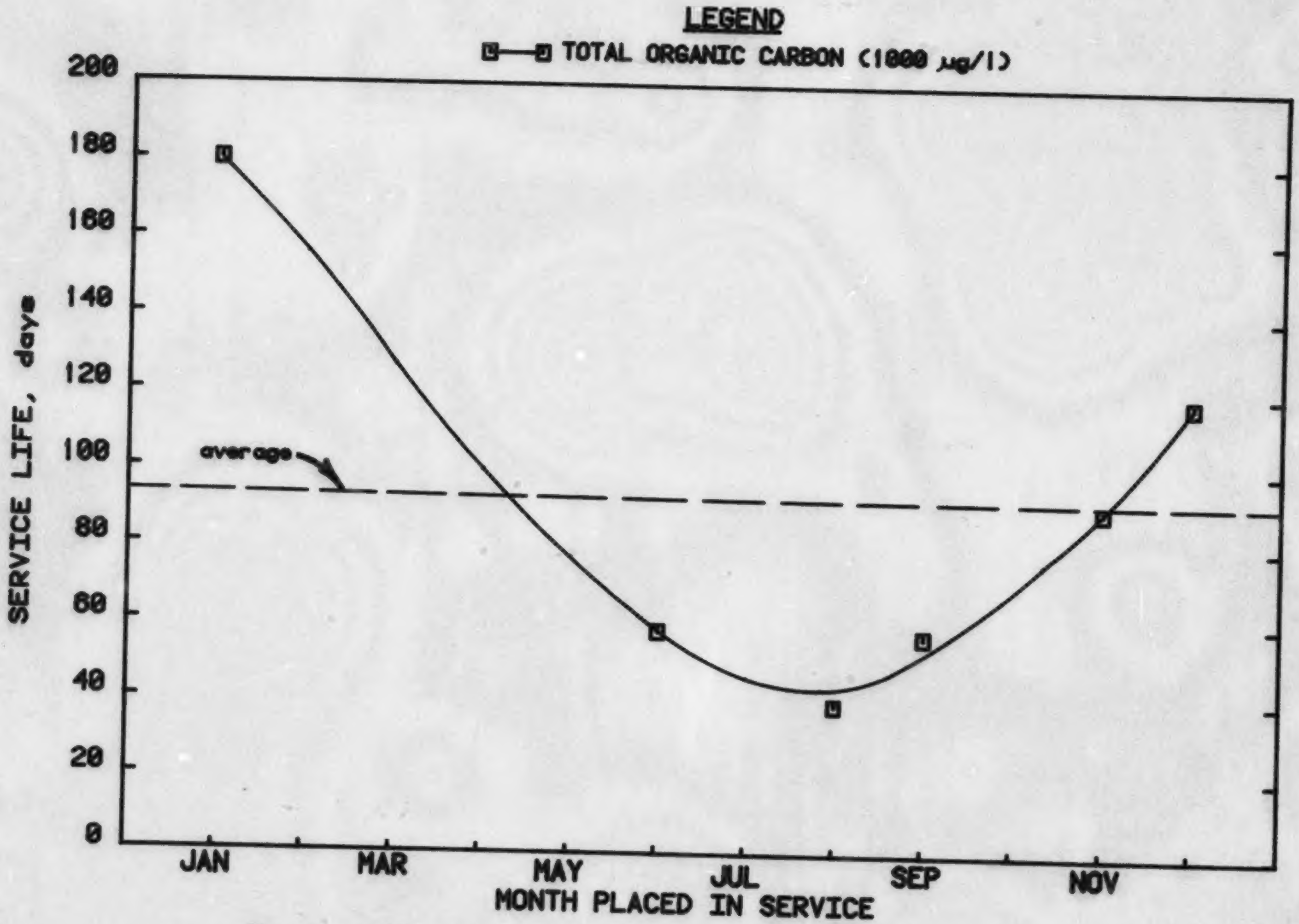


Figure 119. Contactor service life, 1980.

be approximated by referring to Figure 115. It can be assumed that the maximum reduction in GAC utilization which might occur between EBCTs of 15 and 20 minutes would exist if carbon use rate improved following the same slope exhibited between 7.2 and 15.2 minutes EBCT. Extrapolation of the critical carbon use rate curve in Figure 115, Contactor C (3-1) indicates that GAC utilization might be reduced to as low as 102 kg/mil l (850 lb/mil gal) during the summer. This corresponds to a single contactor service life of approximately 67 days (calculated from Figure 115's carbon use rate) or 134 days for contactors in staggered operation.

Since average annual carbon use rate data was not generated for a 20 minute EBCT, an interpolation of the average of all Phase 3 runs contained in Figure 115 was used as a surrogate. Accordingly, a carbon use rate of 20 kg/mil l (165 lb/mil gal) (one-half of the Figure 115 value) was obtained.

Backwash requirement--As indicated under "surface loading", backwashing was not required during the study period. Backwash facilities are necessary, however, to remove GAC fines after initial filling and to fluidize the bed for GAC removal.

A backwash rate of 6.8 lps/sq m (10 gpm/sq ft) was utilized for contactors and proved satisfactory. Backwashing was initiated at 2.0 lps/sq m (3 gpm/sq ft) for five minutes, then 4.1 lps/sq m (6 gpm/sq ft) for five minutes, followed by two periods at 6.8 lps/sq m (10 gpm/sq ft) of 20 and 15 minutes each with five minutes settling between the two.

Regeneration requirements--GAC regeneration capacity is controlled by summer operation when maximum water production is required and GAC service life is at a minimum. Regeneration capacity must, therefore, be sufficient to handle the daily production of spent GAC at the maximum monthly average flow and the carbon use rate resulting from critical summer contactor service life.

Standby contactor capacity--Removal of spent GAC and replacement with regenerated or virgin GAC necessitates that the contactor be out of service for a period of time each cycle. Sufficient standby contactor capacity must be provided to compensate for this lost capacity. The maximum capacity out of service at one time will be that resulting from maximum monthly average water production and critical summer contactor service life, multiplied by the expected duration of downtime for GAC removal and replacement. As indicated in Objective 13, one additional contactor would be required.

Design considerations--

GAC handling and transport--GAC was removed from the contactors by fluidizing the GAC bed and utilizing hydraulic pressure to force out the GAC slurry. An additional point of water injection was installed at the GAC outlet to adequately fluidize the GAC so that the slurry would flow. The contactor vessels had dished bottoms which were below the level of the treated effluent header. GAC in the dished portion could not be adequately fluidized, which resulted in difficulties.

GAC transport piping was extra-strong black steel pipe with forged steel flanges and fittings. All valves in the transport system were full-port stainless steel ball valves with Teflon seats. This appears to have been a satisfactory application.

Process pumps and piping--Ordinary water plant pumps, piping, valves and rate controllers were used with contactors. This project yielded the following observations which might be considered in future designs:

1. Contactor backwash discharge ports should be located above the expanded bed when backwashing to eliminate GAC loss. Screens did not function properly because of clogging problems.

2. The contactor effluent header should be lower than the bottom of the contactor to allow draining and removal of transport water. If this is not desirable from a design standpoint, a separate line must be installed.

3. Air and vacuum relief valves must be adequately sized for the capacities of air required.

4. Turbulence in the piping downstream from the rate-of-flow controller caused cavitation problems with the piping. This was due to abrupt changes in flow direction both upstream and downstream from the valve, the position of the axis of the valve in relation to the flow, and the sizing of the valve. In designing rate controllers and piping, attention should be given to all factors that are normally considered for a valve used to throttle flows. Proper sizing and piping arrangement should eliminate these problems.

5. The piping layout did not permit adequate isolation for working on all sections of piping and valves without taking the entire installation out of service.

Materials of construction--All equipment that will not be in contact with GAC can be constructed of materials normally used for water treatment plants. The contactors must be designed using materials or liners that do not impart objectionable organics to the water and are resistant to abrasion and chemical attack by GAC.

Related plant modifications--The installation of contactors will require additional modifications to existing facilities. The extent of these modifications are site specific. New pumping facilities may be required to relay filtered water to the contactor facilities. Additional washwater or GAC transport water facilities may be required. Post-chlorination will be necessary, possibly requiring additional chlorine contact time.

On-site GAC Regeneration--

Design criteria--

Regeneration capacity--Regeneration capacity must be sufficient to meet the demands of summer operation. Furnace downtime must be factored into the design capacity. During this study, the regeneration system was operable approximately 60% of the time. Experience at other installations has indicated continued improvement in operating efficiency with time. Taking this potential improvement into consideration, 70% operation appears reasonable for design.

Make-up GAC storage--Transport and regeneration of GAC results in losses due to incineration and carry-over of fines in motive water. Adequate virgin GAC must be stored on site to replace regeneration losses. Transport and regeneration losses for GAC filters averaged 18.5%. Losses for contac tors averaged 15.3%. The higher losses from GAC filters were due to longer transfer piping runs, shovel handling of GAC and sand separator inefficiency.

Sand removal--A vibrating sand separator table was utilized to separate sand from GAC prior to filter regeneration. The separator was adjusted by regulating the flow of water to the table and the slope of the table top. Difficulties were encountered in this operation since sand accumulated in the dryer and regeneration sections of the furnace which necessitated shutting the furnace down for manual removal of sand. Future designs of full-scale facilities should evaluate alternative methods of sand removal.

Design considerations--

Process considerations--Several observations were made during the course of this study which should be considered in future designs.

1. Off-gases from the dryer section of the regeneration furnace passed through a cyclone separator and were then reintroduced into the incineration zone of the furnace prior to discharge to the atmosphere through a venturi scrubber. Incineration of off-gases was utilized to ensure that organics were not discharged to the atmosphere. Analysis of the dryer off-gases indicated insufficient low temperature volatiles to justify the required secondary burner ("Other Observations" section). Fuel consumption would be substantially reduced by eliminating this feature of furnace design. Results from this study should be compared to those obtained from other installations.

2. A number of regeneration system operating problems were related to the computerized control system. The sophisticated control package made manual control difficult and resulted in substantial down-time. Future designs should consider various control options.

3. Regardless of regenerator size, a minimum of three furnaces would be recommended for a full-scale installation. This would increase

flexibility of operation and would provide standby capacity during maintenance.

4. The slurry pump used to transport GAC from the regeneration system required injection of additional water to create the proper fluidity. Backpressure created by thick GAC slurry resulted in separation of the connecting hoses and in a long section of piping becoming clogged with thick GAC paste.

Ancillary facilities--The regeneration system requires adequate power, fuel, water, and air to support the installation. A source of softened water is necessary for generation of steam which is used for bed fluidization. Consideration must also be given to handling the quantities of motive water which must be returned to the treatment process. Disposal of GAC fines removed by the cyclone and scrubber gas streams must also be evaluated. An overhead crane and large access doors are required to aid installation and maintenance of the regeneration system.

Objective 13. To Determine Costs of Research Experience and Project Costs of Full-Scale Plant Conversion

Costs Developed Under Research Conditions--

Although the costs developed under this section were real costs, they can be misleading and should not be considered as indicative of the costs to convert to full-scale operations. Factors which must be considered in qualifying the costs developed in this section include:

1. The facilities were built primarily for research purposes adding significantly to their cost.

2. The plant evaluated under this section compared a 0.44 cu m/s (10 mgd) GAC filter system with a 0.17 cu m/s (4 mgd) contactor system, the actual configuration operated during Phase 3. Differences of scale were compensated to some extent by calculating costs per 3,785 l (1,000 gal).

3. The application of GAC in filters would require the addition of filters and GAC storage to compensate for the reduction in plant capacity due to frequent filter changeovers for regeneration.

4. The furnace built for this grant was oversized relative to 0.44 cu m/s (10 mgd) and 0.17 cu m/s (4 mgd) adsorption systems. Had there been additional GAC to regenerate, the furnace capacity would have allowed about 272 metric tons (300 short tons)/yr more to be regenerated over the optimum levels presented in this section. Therefore, the optimum costs for GAC regeneration would have been about 11¢/kg (5¢/lb) less.

5. Maintenance costs were practically non-existent during the grant since most systems were new and covered by warrantees. This was hardly a real life situation.

The effect of these other factors will be addressed in the next section of this report.

Tables 66 through 68 show some of the pertinent background data used in the cost calculations that will be subsequently discussed. The useful life cycles shown on Table 66 were estimated by CWW personnel based on normal operating experiences gained to date. These were used in the calculation of "actual" costs. Costs were also calculated using a straight 20-year life and were used in the calculation of "optimum" costs. Costs incurred during the years 1979 and 1980 were summarized for use in the "research condition" part of this objective.

"Actual" costs are defined as those costs actually incurred during a time frame most representative of "normal" operations under this grant. These costs reflect the fact that the filters and contactors were not regenerated or otherwise operated exactly according to plan (for reasons indicated in other sections of this report). "Optimum" costs reflect costs that would have been incurred if the operating and regeneration plan (primarily a six week-cycle for a filter and a three-month cycle for a contactor) had been rigidly adhered to.

No capital costs or electrical operating costs were included for GAC filters because no additional costs were incurred above what was normally required for a sand filter. Thus the costs shown reflect only the additional costs required by the use of either GAC system. The sand replacement transport system was manually fed and contributes to GAC losses through excessive handling. In a full-plant conversion, capital expenditures for a more efficient transport system would be a wise investment.

TABLE 66. USEFUL LIFE ESTIMATES FOR CAPITAL COST DATA

GAC Filters

Initial GAC Inventory - 20 year life

Contactors

Initial GAC Inventory - 20 year life
Contactors and Instrumentation - 8 year life
Building - 25 year life

Regenerator

Furnace, Tanks & Controls - 15 years
Building - 25 years

All unit capital costs are amortized at 10% over the useful life span indicated.

TABLE 67. COST FACTORS

	Metric		English	
Power	2.19- 2.91 ¢/kWh		2.19- 2.91 ¢/kWh	
Natural Gas	11.1 -11.9 ¢/cu m		31.0 -33.8 ¢/ccf	
Water	11.1 ¢/cu m		42.2 ¢/1,000 gal	
GAC	1.08- 1.17 $/kg		49 -53 ¢/lb	
Labor				
Contactor & Furnace	8 $/hr		8 $/hr	
General Labor	6.50 $/hr		6.50 $/hr	
Maintenance	7 - 9 $/hr		7 - 9 $/hr	
Natural Gas Fuel Value	35,300 BTU/cu m		1,000 BTU/cu ft	
Reactivation Fuel Use	13,200 BTU/kg GAC		6,000 BTU/lb GAC	
	Actual	Optimum	Actual	Optimum
Furnace Throughput				
GAC Filters	378 mt/yr	542 mt/yr	416 t/yr	596 t/yr
Contactors	295 mt/yr	233 mt/yr	324 t/yr	256 t/yr
Total	673 mt/yr	775 mt/yr	740 t/yr	852 t/yr
GAC Systems Throughput				
GAC Filters	9,008 mil l/yr	11,165 mil l/yr	2,380 mgy	2,950 mgy
Contactors	4,542 mil l/yr	5,300 mil l/yr	1,200 mgy	1,400 mgy
Total	13,550 mil l/yr	16,465 mil l/yr	3,580 mgy	4,350 mgy

The capital costs and annual operating costs of the reactivation system are shown in Tables 69 and 70 along with the costs of the adsorption system. Also, the capital and operating costs of the reactivation system were prorated between the two adsorption systems based on the ratio of actual and optimum GAC throughput for each adsorption system to the total throughput.

Operational labor and materials were primarily related to GAC transport and make-up GAC, respectively. The backwash criterion of 138 kPa (20 psig) head loss (developed during pilot column tests) was never exceeded in the contactors during the study period. Therefore, the contactor system pumping costs primarily consist of influent pumping.

Table 71 shows a comparison of the annual amortized capital costs based on the useful life cycles shown in Table 66 (actual) and a straight 20 year life (optimum). The major difference appears in the contactor system data

TABLE 68. DETAILED CAPITAL COSTS

	Cost in Dollars
Building	
Foundation & Tunnel	$ 70,700
Building Heat., Vent. & Light	175,190
Floor & Drain System	52,100
Potable Water Piping	3,080
Final Connections	8,160
Misc.	4,210
Engineering, Design	44,520
Engineering, Resident	20,970
Total Building	$ 378,940
Contactors	
Pressure Vessels (4)	$ 355,550
Sample Troughs	24,310
Influent/Effluent Piping	156,380
Process Pumps	37,370
Backwash Piping	77,490
GAC Transport Piping	60,100
Compressed Air Equip.	38,130
Switchgear	53,500
Painting	12,100
Engineering, Design	82,920
Engineering, Resident	16,540
GAC Installation Labor	920
Initial GAC	85,290
Total Contactors	$1,000,600
GAC Filters (2)	
Sand Removal Labor	2,000
GAC Installation Labor	1,400
Sample Units	11,190
Turbidimeters	2,030
Initial GAC	96,250
Total GAC Filters	$ 112,870
Regenerator	
Furnace	248,230
Instrumentation	224,500
Storage Tanks (2)	53,650
Steam Generator and Piping	14,900
Sand Separator	13,850
Motor Control Center & Wiring	17,010
Water Piping	9,810
Drain Piping	7,220
GAC Transport Piping	38,900
Engineering, Design	84,780
Engineering, Resident	7,410
Final Connections	38,630
Total Regenerator	$ 758,890
Total Capital Costs	$2,251,300

TABLE 69. CAPITAL COST SUMMARY[a]

	GAC Filters 0.44 cu m/s (10 mgd)		Contactors 0.17 cu m/s (4 mgd)		Reactivation 230 kg/hr (500 lb/hr)	
	Actual	Optimum	Actual	Optimum	Actual	Optimum
Construction	$ 16,620	$ 16,620	$ 915,310	$ 915,310	$758,890	$758,890
Building Cost	-	-	189,470	189,470	189,470	189,470
Initial GAC	96,250	96,250	85,290	85,290	-	-
Total Capital Cost	112,870	112,870	1,190,070	1,190,070	948,360	948,360
Prorated Reactivation	531,080	663,850	417,280	284,510	-	-
Total Costs	$643,950	$776,720	$1,607,350	$1,474,580	-	-

[a] Land, legal, fiscal and administrative and insurance costs were not included.

because of the eight-year life estimated for the entire contactor system. The total annualized operating and capital costs are shown in Table 72 in dollars and in Table 73 in ¢/1000 gal of water throughput or ¢/lb of GAC throughput. The criterion of a six-week or a three-month bed life must be kept in mind when considering the optimum costs shown. Relaxed criteria would result in lower costs, with reduced water quality being delivered. The actual and optimum costs including prorated on-site reactivation, were 3¢/cu m (13¢/1000 gal) and 4¢/cu m (14¢/1000 gal), respectively, for the GAC filter system and 10¢/cu m (36¢/1000 gal) and 6¢/cu m (23¢/1000 gal), respectively, for the contactor system. The actual and optimum GAC reactivation costs were 21¢/lb and 19¢/lb, respectively, based on an annual GAC throughput of about 740 tons and 852 tons, respectively.

These data should approximate the actual costs involved in design, construction and operation of a system that would be full-scale for many utilities.

In consideration of the disclaimers listed at the beginning of this section, it would not be prudent to accept the apparent cost advantage of the GAC filters. As indicated in Table 72, although the GAC filters had greater annual operating costs, the greater capital costs associated with constructing the contactors easily tipped the scales in favor of the GAC

TABLE 70. PRELIMINARY ANNUAL OPERATING AND MAINTENANCE COSTS

	GAC Filters 0.44 cu m/s (10 mgd)		Contactors 0.17 cu m/s (4 mgd)		Reactivation 230 kg/hr (500 lb/hr)	
	Actual	Optimum	Actual	Optimum	Actual	Optimum
Water						
GAC Transport	$ 1,380	$ 1,930	$ 980	$ 930	-	-
Process	-	-	-	-	14,800	17,000
Electric						
Pumping	-	-	12,670	14,790	-	-
Building	-	-	3,810	3,810	3,810	3,810
Furnace	-	-	-	-	4,440	5,100
Nat'l. Gas	-	-	-	-	35,520	40,900
Operating Labor						
GAC Filters	29,400	41,160	-	-	28,000	39,200
Contactors	-	-	18,110	17,680	22,850	21,700
Furnace	-	-	-	-	12,500	12,500
Operating Mat'l.	97,400	136,360	53,920	51,220	-	-
Mtce. Labor	-	-	-	-	66,850	66,850
Mtce. Mat'l.	-	-	-	-	1,540	1,540
Subtotal	$128,180	$179,450	$ 89,490	$ 88,430	$190,310	$208,600
Related React. Costs	28,000	39,200	22,850	21,700	-	-
Prorata React. Costs	78,100	103,390	61,360	44,310	-	-
Totals	$234,280	$322,040	$173,700	$154,400		

filters. Also, as indicated in Table 73, the greater annual throughput rendered further advantage to the GAC filters wherein even the operating cost per 1000 gal was lower. An attempt to compensate for the disclaimers was made in the next section.

TABLE 71. COMPARISON OF ANNUAL AMORTIZED CAPITAL COSTS

	Actual Based on Useful Life	Optimum Based on 20 Year Life
GAC Filters	$ 13,260	$ 13,260
Contactors	202,460	139,790
Reactivation System	120,650	111,390
Prorated Reactivation System		
GAC Filters	67,560	77,970
Contactor	53,090	33,420
Total Costs		
GAC Filters & Reactivation	$ 80,820	$ 91,230
Contactors & Reactivation	$255,550	$173,210

TABLE 72. TOTAL ANNUAL COSTS RECAP

	GAC Filters 0.44 cu m/s (10 mgd)		Contactors 0.17 cu m/s (4 mgd)		Reactivation 230 kg/hr (500 lb/hr)	
	Actual	Optimum	Actual	Optimum	Actual	Optimum
Operating	$128,180	$179,450	$ 89,490	$ 88,430	$190,310	$208,600
Capital	13,260	13,260	202,460	139,790	120,650	111,390
Subtotal	$141,440	$192,710	$291,950	$228,220	$310,960	$319,990
Prorated React.						
Operating	$106,100	$142,590	$ 84,210	$ 66,010		
Capital	67,560	77,970	53,090	33,420		
Subtotal	$173,660	$220,560	$137,300	$ 99,430		
Total Annual Costs	$315,100	$413,270[a]	$429,250	$327,650		

Proration of reactivation costs determined by adding prorata shares recorded in Table 62.

[a] This "optimum" is higher than "actual" since under optimum operating conditions much greater amounts of makeup GAC and regenerated GAC would have been used.

TABLE 73. UNIT COSTS RECAP

	¢/1000 gal water throughput[a]				¢/lb GAC throughput[b]	
	GAC Filters 0.44 cu m/s (10 mgd)		Contactor 0.17 cu m/s (4 mgd		Reactivation 230 kg/hr (500 lb/hr)	
	Actual	Optimum	Actual	Optimum	Actual	Optimum
Operating	5.3	6.1	7.5	6.3	12.9	12.3
Capital	0.6	0.4	16.9	10.0	8.1	6.5
Subtotal	5.9	6.5	24.4	16.3	21.0	18.8
Prorated React.						
Operating	4.5	4.8	7.0	4.7		
Capital	2.8	2.7	4.4	2.4		
Subtotal	7.3	7.5	11.4	7.1		
Total	13.2	14.0	35.8	23.4		

[a] To determine ¢/1000 l divide figures by 3.8.
[b] To determine ¢/kg multiply figures by 2.2.

Cost projections for full-plant conversion--

General--Conceptual cost estimates have been prepared for CWW in order to determine the magnitude of costs of GAC treatment at a major water treatment facility. The plant has a design capacity of 10.3 cu m/s (235 mgd) utilizing 47 rapid sand filters rated at 0.2 cu m/s (5 mgd) each. Design average flow (maximum monthly average) is 8.8 cu m/s (200 mgd).

Estimates or probable costs have been developed for GAC filters and contactors, each with on-site regeneration facilities. Where applicable, data collected during this study have been utilized for sizing the required facilities and estimating costs. Cost data from a previous USEPA study[27] were also used extensively. Operating and maintenance cost increases were developed using the factors presented in Table 74 and current annual average water production of 5.7 cu m/s (140 mgd). Labor costs were developed by estimating the number and classification of additional employees required to operate and maintain the expanded facilities. All costs developed in the "full plant conversion" part of this objective were based on September, 1981 dollars and on preliminary conceptual designs and assumptions (Objective 12).

GAC filters--Two alternatives were considered in evaluating GAC filter systems. One alternative was based on controlling TOC at less than

TABLE 74. OPERATING AND MAINTENANCE COST FACTORS

Electricity	$ 0.04 kWh
Natural Gas[a]	$ 0.12/cu m ($0.34/100 cf)
Service Water	$ 0.13/cu m ($0.50/1,000 gal)
GAC	$ 1.87 kg ($0.85/lb)
Average Labor Rate (inc. fringes)	$ 12.50/hr
Chlorine	$264 /mt ($240.00/ton)
GAC Transport Water	8.34 l/kg GAC (1 gal/lb GAC)
Regeneration Electricity	0.13 kWh/kg GAC (0.06 kWh/lb GAC)
Regeneration Natural Gas	4.2 joule/kg (2,000 Btu/lb GAC)
GAC Regeneration Loss	18.5 %

[a] At local utility quote of 1,000 Btu/cu ft.

1,000 μg/l and the other at TOC less than 1,500 μg/l. Both alternatives ensure continued control of THMSIMDIST. GAC filters would operate at 1.7 lps/sq m (2.5 gpm/sq ft), providing 7.5 minutes EBCT.

GAC filter service lives were developed in Objective 12. However, because the study included a limited number of runs, it would seem prudent to incorporate a safety factor in a full-scale design. Summer critical GAC filter service lives used in this evaluation have been reduced by approximately 15% to allow for this uncertainty.

A system to reduce TOC to less than 1,000 μg/l could be designed for service lives of 14 days in the summer (85% of twice the summer critical values shown in Table 63). Maximum monthly average water production of 4.4 cu m/s (200 mgd) requires that 40 filters be in service. A 14-day summer service life would, therefore, necessitate removing three GAC filters from service each day for replacement of spent GAC. Assuming two days downtime for GAC replacement, six additional filters would be required to maintain the same plant capacity. Daily regeneration capacity must be sufficient to handle spent GAC from three filters, each containing 48,500 kg (106,750 lb). Assuming a 70% regenerator design service factor (uptime), required regeneration capacity would be 204,000 kg/day (450,000 lb/day).

A system designed to reduce TOC to less than 1,500 μg/l could be designed for service lives of 31 days in the summer (85% of twice the summer critical values shown in Table 63). Operation of this system would require that three GAC filters be removed from service every two days during the summer for replacement of spent GAC. Assuming two days downtime per GAC filter for servicing, three additional filters would be required to maintain the same plant capacity. Regeneration capacity would be needed to handle spent GAC from 1.5 filters [72,700 kg (160,125 lb)] daily. A design capacity of 104,400 kg/day (230,000 lb/day) would provide the required firm capacity at 70% uptime.

Table 75 presents a design summary of the two treatment alternatives. Each alternative includes conversion of the existing 47 rapid sand filters by replacing the filter sand with GAC and installing GAC handling facilities. Additional GAC filters would be constructed for either alternative, would be the same configuration as the modified units and would include surface washing facilities. Preliminary calculations indicate that additional backwashing facilities would not be required. Handling facilities would include spent GAC removal troughs at the support gravel/GAC interface, spent GAC transport piping and pumps and fresh GAC return piping. Regeneration facilities would include multiple fluid bed furnaces housed in a separate building along with spent and regenerated GAC storage, associated support facilities, and controls. Virgin make-up GAC would be stored in cone-bottomed vessels housed with the regeneration facilities. Post-chlorination requirements would include new chlorine storage and feed facilities ahead of the clearwells. Baffling would be installed in the clearwells to prevent short-circuiting and to make full use of available contact time. Also, high service pumping facilities for two small service areas must be relocated from the filter effluent flume to the clearwells to ensure adequate chlorine contact.

Estimated costs for the two GAC filter treatment alternatives are presented in Table 76. Capital costs were amortized at an interest rate of 10 percent over 20 years. This cost summary indicates that treatment to reduce TOC to less than 1,000 µg/l will result in an increased cost of approximately 6¢/cu m (24¢/1,000 gal). Providing treated water with TOC less than 1,500 µg/l will result in increased costs of approximately 3¢/cu m (13¢/1,000 gal).

Contactors--Two alternatives were also considered in evaluating contactors. However, the two alternatives considered for GAC filters (i.e. 1,000 and 1,500 µg/l TOC) could not be evaluated since the TOC effluent concentrations in the contactors rarely exceeded 1,500 µg/l. Further, unlike the existing filters, new contactors could be designed at an optimum EBCT. Therefore, alternatives were based on providing a finished water containing less than 1,000 µg/l TOC with one system providing 15 minutes EBCT and the other 20 minutes EBCT. Both systems would ensure continued control of THMSIMDIST. A preliminary investigation of pressure contactors versus gravity contactors indicated that concrete gravity contactors would be more cost-effective for this size installation. For this reason, gravity contactors designed for 3.4 lps/sq m (5 gpm/sq ft) were utilized as the basis for these alternatives.

Data from this study was used to develop design criteria for full-scale contactors. Contactor summer critical service lives used in this evaluation have been reduced by a safety factor of 15% since the study contained a limited number of runs.

The alternative providing 15 minutes EBCT is assumed to have a service life of 66 days during the summer (85% of twice the summer critical value shown in Table 65). The system includes 25 contactors rated at 0.44 cu m/s

TABLE 75. CONCEPTUAL DESIGN SUMMARY FOR GAC FILTERS

	Treatment Goal	
	1,000 μg/l TOC	1,500 μg/l TOC
GAC Filters:		
Surface Area	130 sq m (1,400 sq ft)	130 sq m (1,400 sq ft)
Hydraulic Loading	1.7 lps/sq m (2.5 gpm/sq ft)	1.7 lps/sq m (2.5 gpm/sq ft)
Empty Bed Contact Time	7.5 min	7.5 min
Critical Summer Serv. Life	14 days	31 days
Annual Avg. Carbon Use Rate	96 kg/mil l (800 lbs/mil gal)	42 kg/mil l (350 lbs/mil gal)
Number Units Req'd. -		
Existing	47	47
New	6	3
GAC per Unit	48,500 kg (106,750 lb)	48,500 kg (106,750 lb)
GAC Regeneration:		
Max. Spent GAC	145,400 kg/day (320,250 lb/day)	72,700 kg/day (160,125 lb/day)
Regenerator Capacity	204,000 kg/day (450,000 lb/day)	113,500 kg/day (250,000 lb/day)
Number Furnaces Req'd.	9	5
Furnace Capacity	22,700 kg/day (50,000 lb/day)	22,700 kg/day (50,000 lb/day)
Spent GAC Storage Capacity	204,000 kg (450,000 lb)	113,500 kg (250,000 lb)
Regen. GAC Storage Cap.	204,000 kg (450,000 lb)	113,500 kg (250,000 lb)
Virgin GAC Storage:		
Assumed Regeneration & Transport Loss	18.5 %	18.5 %
Max. Make-up GAC	28,900 kg/day (59,250 lb/day)	13,450 kg/day (29,620 lb/day)
Annual Avg. Make-up GAC	11,360 kg/day (25,000 lb/day)	5,000 kg/day (11,000 lb/day)
Storage Capacity	113,500 kg (250,000 lb)	50,000 kg (110,000 lb)
Post-Chlorination:		
Cl_2 Storage & Feed Cap.	4,450 kg/day (9,800 lb/day)	4,450 kg/day (9,800 lb/day)
Contact Time[a]	2.5 hr	2.5 hr

[a] At 893 kcu m (235 mgd).

TABLE 76. COST ESTIMATES FOR FULL-SCALE CONVERSION OF PLANT TO GAC FILTERS

	Treatment Goal	
	1,000 μg/l TOC	1,500 μg/l TOC
Capital Costs		
Convert Existing Filters	$ 3,800,000	$ 3,800,000
Additional GAC Filters	3,500,000	2,200,000
Regeneration System	17,000,000	9,500,000
Make-up GAC Storage	250,000	150,000
Chlorine Storage and Feed	450,000	450,000
Chlorine Contact Modifications	1,500,000	1,500,000
Miscellaneous Site Work	1,300,000	900,000
Contractor Overhead & Profit	2,400,000	1,700,000
Engineering, Legal & Administrative	2,300,000	1,600,000
Initial GAC Inventory	4,800,000	4,500,000
Total Capital Cost	$37,300,000	$26,300,000
Annual Amortized Capital Cost[a]	$ 4,381,260	$ 3,089,200
Annual O & M Cost		
Natural Gas	$ 300,000	$ 130,000
Electricity	180,000	90,000
Maintenance Material	380,000	200,000
Service Water	50,000	30,000
Chlorine	100,000	100,000
Make-up GAC	6,450,000	2,830,000
Labor	570,000	360,000
Total Annual O & M[b]	$ 8,030,000	$ 3,740,000
Total Annual Cost[b]	$12,411,260	$ 6,829,200
Cost Increase per cu m[b]	$ 0.063	$ 0.036
Cost Increase per 1,000 gal[b]	$ 0.240	$ 0.135

[a] Amortized at 10% for 20 years.

[b] Based on current average of 5.7 cu m/s (140 mgd).

(10 mgd) each having a GAC bed depth of 3 m (10 ft) and a surface area of 39.6 sq m (1,400 sq ft). Design capacity flow of 10.3 cu m/s (235 mgd) would require 24 contactors in service with maximum average production of 88 cu m/s (200 mgd) requiring 20 units. At the critical service life of 66 days, one contactor would be taken out of service approximately every third day for GAC removal and replacement. Assuming that removal of spent GAC and

replacement with fresh requires that the unit be out of service no more than three days, one spare contactor would be sufficient. Regeneration capacity must handle one-third of a contactor each day. Assuming a 70% uptime, the required capacity would be 90,800 kg/day (200,000 lb/day).

The 20-minute EBCT alternative was extrapolated (Objective 12) to have a summer service life of 114 days. This system also includes 25 contactors rated at 0.44 cu m/s (10 mgd) each having a GAC bed depth of 4 m (13.5 ft) and a surface area of 130 sq m (1,400 sq ft). Peak design flow of 10.3 cu m/s (235 mgd) would require 24 contactors on line with maximum monthly average flow of 8.8 cu m/s (200 mgd) requiring 20 units. At a service life of 114 days, one contactor would be taken out of service approximately every six days. Assuming that removal and replacement of spent GAC would require that the unit be out of service no more than four days, a single spare contactor would be needed. Regenerator capacity of 63,500 kg/day (140,000 lb/day) would provide sufficient capacity to regenerate one-sixth of a contactor daily at 70% uptime.

Table 77 presents a design summary of the two contactor alternatives. Each includes intermediate pumping to transfer filter effluent to the contactor facility. The contactors would be similar in configuration to the existing sand filters but would be equipped with GAC removal troughs at the interface of the support gravel and the GAC bed. Facilities would be provided to transport spent GAC to the regeneration facilities and to return fresh GAC to the contactors. The entire contactor complex would be housed. On-site regeneration would include sufficient spent and regenerated GAC storage to hold the contents of an entire contactor. Each alternative would include four fluid bed furnaces and associated support facilities and controls. Virgin make-up GAC would be stored in cone-bottomed vessels which would be housed in a complex with the regeneration furnaces and spent and regenerated GAC storage facilities. Backwashing and transporting spent GAC from the contactors would require washwater in addition to the normal requirement for the sand filters. Each alternative includes 3.8 mil l (1 mil gal) additional washwater storage capacity. Post-chlorination facilities would include new chlorine storage and feed ahead of the existing clearwells as well as installation of baffling in the clearwells to prevent short-circuiting. High service pumping suction for two small service areas would also require relocation from the sand filter effluent flume to the clearwells to provide GAC-treated and chlorinated water to these areas. Because the USEPA cost curves[27] assumed a sand/gravel base under the contactors, the assumed regeneration and transport loss of 18.5% for the GAC filters was also used for the contactors. The sand/gravel base in the GAC filters was believed responsible for the higher GAC filter losses.

Relative costs for the two contactor alternatives are presented in Table 78. Capital costs were amortized at ten percent over 20 years. Annual operation and maintenance expenses were based on current water production averaging 6.2 cu m/s (140 mgd).

The outcome of the economic analysis presented in Table 78 indicates that both 15 and 20-minute EBCT alternatives will result in increased costs

TABLE 77. CONCEPTUAL DESIGN SUMMARY FOR CONTACTORS

	EBCT, 15 min	EBCT, 20 min
Intermediate Pumping:		
Design Capacity	10.3 cu m/s (235 mgd)	10.3 cu m/s (235 mgd)
Contactors:		
Surface Area	130 sq m (1,400 sq ft)	130 sq m (1,400 sq ft)
Hydraulic Loading	3.4 lps/sq m (5 gpm/sq ft)	3.4 lps/sq m (5 gpm/sq ft)
GAC Bed Depth	3 m (10 ft)	4.1 m (13.5 ft)
Critical Summer Serv. Life	66 days	114 days
Annual Avg. Carbon Use Rate	34 kg/mil l (285 lbs/mil gal)	20 kg/mil l (165 lbs/mil gal)
Number Units Req'd.	25	25
GAC per Unit	193,860 kg (427,000 lb)	261,700 kg (576,450 lb)
GAC Regeneration:		
Max. spent GAC	64,620 kg/day (142,330 lb/day)	43,620 kg/day (96,075 lb/day)
Regenerator Capacity	90,800 kg/day (200,000 lb/day)	63,560 kg/day (140,000 lb/day)
Number Furnaces Req'd.	4	4
Furnace Capacity	22,700 kg/day (50,000 lb/day)	15,900 kg/day (35,000 lb/day)
Spent GAC Storage Capacity	195,220 kg (430,000 lb)	263,320 kg (580,000 lb)
Regen. GAC Storage Cap.	195,220 kg (430,000 lb)	263,320 kg (580,000 lb)
Virgin GAC Storage:		
Assumed Regenerated & Transport Loss	18.5 %	18.5 %
Max. Make-up GAC	12,000 kg/day (26,330 lb/day)	8,100 kg/day (17,770 lb/day)
Annual Avg. Make-up GAC	1,076 kg/day (8,960 lb/day)	623 kg/day (5,190 lb/day)
Storage Capacity	10,808 kg (90,000 lb)	6,245 kg/day (52,000 lb)
Additional Backwash Storage:		
Storage Capacity	3,785 cu m (1 mgd)	3,785 cu m (1 mgd)
Post-Chlorination:		
Cl_2 Storage & Feed Cap.	4,450 kg/day (9,800 lb/day)	4,450 kg/day (9,800 lb/day)
Contact Time[a]	2.5 hr	2.5 hr

[a] At 893 kcu m (235 mgd).

TABLE 78. COST ESTIMATES FOR FULL-SCALE CONVERSION OF PLANT TO CONTACTORS

	EBCT, 15 min	EBCT, 20 min
Capital Costs		
Intermediate Pumping	$ 1,700,000	$ 1,700,000
Contactor Facilities	10,800,000	12,000,000
Regeneration System	7,900,000	7,800,000
Make-up GAC Storage	150,000	100,000
Chlorine Storage and Feed	450,000	450,000
Chlorine Contact Modifications	1,500,000	1,500,000
Additional Washwater Storage	1,100,000	1,100,000
Miscellaneous Site Work	1,200,000	1,200,000
Contractor Overhead & Profit	2,200,000	2,300,000
Engineering, Legal & Administrative	2,400,000	2,500,000
Initial GAC Inventory	9,100,000	12,250,000
Total Capital Cost	$38,500,000	$42,900,000
Annual Amoritized Capital Cost[a]	$ 4,522,210	$ 5,039,030
Annual O & M Cost		
Natural Gas	$ 110,000	$ 60,000
Electricity	810,000	840,000
Maintenance Material	280,000	310,000
Service Water	30,000	20,000
Chlorine	100,000	100,000
Make-up GAC	2,290,000	1,330,000
Labor	400,000	400,000
Total Annual O & M Cost[b]	$ 4,020,000	$ 3,060,000
Total Annual Cost[b]	$ 8,542,210	$ 8,099,030
Cost Increase per cu m[b]	$ 0.043	$ 0.042
Cost Increase per 1,000 gal[b]	$ 0.165	$ 0.160

[a] Amortized at 10% for 20 years.

[b] Based on current average of 5.7 cu m/s (140 mgd).

of approximately 4¢/cu m (16¢ per 1,000 gal). Recalling that liberal extrapolations of GAC service life were used to evaluate the 20-minute system, it can be concluded that 15-minute EBCT would likely be more cost effective in actual operation.

Summary--Estimates of probable cost were developed for four alternatives to reduce the presence of synthetic organics in potable water by GAC treatment at CWW as an example of a large facility. These costs were based on conceptual designs and were derived primarily using the USEPA cost curves[27] and operating data from this study.

A comparison of the increased cost to the consumer for the four alternatives is shown in Table 79. This comparison indicates that for a given treatment goal (TOC = 1,000 µg/l), contactors would be more cost effective than GAC filters. Capital costs of the two alternatives would not be significantly different, but operating costs for the GAC filter system would be substantially higher due to less efficient GAC utilization.

As expected, it costs less to meet a less stringent treatment goal (TOC (TOC = 1,500 µg/l vs. TOC = 1,000 µg/l) due to longer GAC service life. Treatment goals of TOC = 1,000 µg/l and TOC = 1,500 µg/l have no known significance regarding the presence of certain undesirable compounds or health risks. Either level of treatment might be acceptable at a given location.

OTHER OBSERVATIONS

Bacterial, Physical, Chemical Observations

Bacterial--

Standard total coliform and total plate count tests were conducted on various sample points throughout the three phases of the project.

Total coliform bacteria were never found in any GAC system influent nor total plant effluent. High total coliform counts, observed in GAC system effluents during Phase 1, are not believed to be true values. Laboratory procedures used during this period were found to be incorrect. After proper procedures were implemented, total coliform counts virtually did not recur during the remainder of the project in any of the GAC systems.

Standard plate counts (SPC) in the influent were generally less than

TABLE 79. COST OF ALTERNATIVE TREATMENT GOALS

GAC System	EBCT, min	Treatment Goal, µg/l TOC	Water Throughput Cost,[a] ¢/1,000 gal
GAC Filter	7.5	1,500	13.5
GAC Filter	7.5	1,000	24.0
Contactor	15.2	1,000	16.5
Contactor	20.0	1,000	16.0

[a] To determine ¢/1,000 l, divide by 3.8.

100/ml, but much higher counts were found in the GAC system effluents (Table 80). These SPC results did not follow any observable trends and support the necessity of post disinfection. As expected, following regeneration, the GAC systems were lower in SPCs for a few weeks.

Physical--

Nothing significant was observed from temperature measurements beyond their expected effect on THM formation.

Compared to chlorinated sand filter effluents, the odor obtained from GAC system effluents in Phases 1 and 2 was better. However, the odor from the GAC system effluents was not better than dechlorinated sand filter effluent samples. In many cases, the odors of both sand and GAC system effluents were musty. The average threshold odor number for the systems tested was around one. Since no real odor problems were detected in the GAC filters of Phase 1 or pilot GAC filters and contactors of Phase 2, this analysis was suspended.

Turbidity values in all phases were as good or better than those of the sand filters and well below the established MCL of 1.0 NTU.

Chemical--

The dissolved oxygen concentration, for the most part, from carbon system effluents followed the influent concentrations. However, the initial dissolved oxygen concentration for both virgin and regenerated GAC in the contactors was very low. Generally, the dissolved oxygen concentration in

TABLE 80. STANDARD PLATE COUNTS PER ML FOR PHASE 3-0

GAC Filter Influent	
Min.	1
Max.	92
Avg.	15
GAC Filter 15A Effluent	
Min.	1
Max.	4,700
Avg.	292
Contactor Influent	
Min.	1
Max.	52
Avg.	3
Contactor D Effluent	
Min.	6.0
Max.	40,800
Avg.	4,840

these systems increased over a two-week period until it approximated the influent concentration.

The average pH of GAC system effluents was slightly lower (pH 8.0) than those of the corresponding influents (pH 8.5). A similar reduction also occurred through the sand filters. Therefore, pH had no significant effect on research results.

The GAC filters removed all but marginal traces of free chlorine. Low concentrations of chloramines passed through the filters with concentration of the 45.7 cm (18 in) GAC filter being noticeably higher. The use of GAC in any plant-wide configuration would require continuous post chlorination.

Several samples were analyzed for pesticides, herbicides and PCBs from various effluents of the pilot and full-scale GAC systems. Raw river and corresponding infuent samples were also analyzed. All results were below the detectable limit of the instrument.

Regenerator Off-Gas Observations

In order to assess the effectiveness of the furnace configuration, which incorporates an incinerator zone with a secondary burner, additional analyses were also requested on samples taken from the dryer off-gas loop (cyclone outlet).

The analytical results of the stack and dryer off-gas sampling are shown in Table 81. After reviewing these data, the Southwest Ohio Air Pollution Authority confirmed that the emission quality was well within the limits established for a process plant.

The analysis of the dryer off-gas loop revealed that insufficient low temperature volatiles existed to justify this feature which required the secondary (incinerator) burner. An inordinate fuel demand was required to maintain process temperatures due to the lack of sufficient combustibles and the loss of heat resulting from the entrained moisture released in drying the GAC.

Data shown on Table 81 indicates that most of the fines which pass through the cyclone were incinerated in the furnace since stack particulate was much lower. At the same time, it appeared that the 149°C (300°F) dryer temperature was not high enough to drive off much of the organic loading, resulting in very little fuel savings attributable to the dryer off-gas loop.

The Work Environment for Fluidized Bed GAC Regenerator Operators

Some concern was expressed by the operators over the airborne GAC particles. The National Institute of Occupational Safety and Health (NIOSH) was contacted to perform a survey of the work environment.

TABLE 81. REGENERATOR OFF-GAS ANALYSES RESULTS

Summary of Average Readings
Grams per Hour (Pounds per Hour)

First Sampling - Contactor

	Stack	Cyclone Outlet
	g/hr (lb/hr)	g/hr (lb/hr)
Particulate		
Filterable	4.5 (0.01)	449.5 (.99)
Condensable	19.5 (0.043)	35.0 (.077)
Methane Equivalent[a]	131.7 (0.29)	0.8 (.0017)
Nitrogen Oxide (Nox)[b]	163.4 (0.36)	N/A

Second Sampling - GAC Filter

	Stack	Cyclone Outlet
	g/hr (lb/hr)	g/hr (lb/hr)
Particulate		
Filterable	4.5 (0.01)	276.9 (0.61)
Condensable	13.6 (0.03)	13.6 (0.03)
Methane Equivalent	81.7 (0.18)	13.6 (0.03)
Nox[c]	202.5 (0.446)	N/A

[a] Total gaseous non-methane organics (TGNMO) is expressed as methane (CH_4) equivalent.

[b] Avg of 12 readings.

[c] Avg of 11 readings.

Since GAC is not classed as a hazardous or toxic material, it was considered a nuisance dust in the findings. Under normal operating conditions, the highest level of dust present was 0.29 mg/cu m, considered an extremely low concentration in view of an allowable 5.0 mg/cu m. Analytical results from organic vapor samples showed no appreciable amount of contamination. Additionally, noise levels within the control room were below the allowable limits set by NIOSH, however, some areas of the building outside of the control room had noise levels which exceeded the standards for continuous (eight-hour) exposure. In view of the fact that operators spend only brief periods outside of the control room, NIOSH determined that this was not a hazard.

Scrubber and Quench Water Analyses

In order to assess the impact of the regeneration process waste water upon any receiving stream, samples were collected from the quench tank and off-gas scrubber water discharge lines on May 13 and 15, 1981. Normally, the source water for the quench tank and the off-gas scrubber was the contactor battery effluent. However, during this period, the source water apparently included a considerable portion of sand filter effluent (SFEF) possibly due to a partially-opened valve. This conclusion was supported by

TOC, INSTTHM and chlorine residual concentrations which were considerably higher than those of contactor effluent water for this period.

Tables 82 and 83 present this physical, chemical and some of the organic data from the samples collected. The tables show a dramatic reduction in the TOC and the INSTTHM concentrations and a slight reduction in the purgeable non-halogenated and CAOX concentrations in the quench water relative to the source water. These reductions were undoubtedly the result of the newly regenerated GAC adsorbing the organics during the short contact time of the quenching operation. The off-gas scrubber water showed a dramatic reduction in INSTTHM concentrations with a slight reduction in the TOC, CAOX and purgeable non-halogenated concentrations. These reductions, along with a reduction in dissolved oxygen were likely due to the elevated temperatures (49.0 and 50.0°C) of the scrubber discharge water. The off-gas analysis (Table 81) did not contain any measurable methane equivalent which would tend to indicate that the reduction in INSTTHM in the off-gas scrubber water does not have a measurable effect on the off-gases. Both the quench and the

TABLE 82. PHYSICAL, CHEMICAL AND ORGANIC DATA FROM MAY 13, 1981 QUENCH AND SCRUBBER SAMPLES

Parameter	Source Water[a]	Quench Tank	Off-gas Scrubber
Temperature, °C	17.0	21.5	49.0
pH	7.5	7.9	5.9
Dissolved Oxygen, mg/l	9.4	6.7	0.9
Turbidity, NTU	0.2	4.6	6.2
Chlorine Residual			
Free, mg/l	b	b	b
Total, mg/l	b	b	b
Hardness, mg/l	143.0	153.0	156.0
TOC, μg/l	1,682	925	1,327
CAOX, μg/l	66	40	b
Hexane, μg/l	c	c	c
Benzene, μg/l	0.2	0.2	c
Toluene, μg/l	c	c	c
Ethylbenzene, μg/l	c	c	c
o-Xylene, μg/l	c	c	c
Tetralin, μg/l	c	c	c
Inst THM			
$CHCl_3$, μg/l	11.1	8.4	0.6
$CHBrCl_2$, μg/l	5.9	2.1	0.2
$CHBr_2Cl$, μg/l	2.0	0.2	c
$CHBr_3$, μg/l	c	c	c

[a] Mixture of SFEF and combined contactor effluents.
[b] Data not available.
[c] Not detected.

TABLE 83. PHYSICAL, CHEMICAL AND ORGANIC DATA FROM MAY 15, 1981 QUENCH AND SCRUBBER SAMPLES

Parameter	Source Water[a]	Quench Tank	Off-gas Scrubber
Temperature, °C	20.5	21.0	50.0
pH	9.1	7.8	6.6
Dissolved Oxygen, mg/l	9.1	6.2	0.7
Turbidity, NTU	0.2	5.6	11.8
Chlorine Residual			
Free, mg/l	0.6	0.0	0.0
Total, mg/l	0.7	0.0	0.0
Hardness, mg/l	144.0	152.0	155.0
TOC, µg/l	1,746	773	1,445
CAOX, µg/l	66	40	41
Hexane, µg/l	0.2	b	b
Benzene, µg/l	0.2	b	b
Toluene, µg/l	b	b	b
Ethylbenzene, µg/l	b	b	b
o-Xylene, µg/l	b	b	b
Tetralin, µg/l	b	b	b
Inst THM			
$CHCl_3$, µg/l	16.0	10.1	1.3
$CHBrCl_2$, µg/l	11.8	2.6	0.4
$CHBr_2Cl$, µg/l	7.3	0.2	0.2
$CHBr_3$, µg/l	0.4	b	b

[a] Mixture of SFEF and combined contactor effluents.
[b] Not detected.

scrubber water samples contained GAC fines as evidenced by the increase in turbidity.

The THMMAX samples from May 13th were lost due to the absence of free chlorine after the seven-day storage period. The May 15th quench and scrubber samples were also devoid of chlorine residual, but in this case, the remainder of the sample was dosed with additional chlorine. Both samples were again devoid of chlorine after another seven days. Once again, chlorine solution was added, but this time only to the scrubber water sample. After another seven days storage, the scrubber water sample was devoid of free chlorine. The quench and scrubber water THMMAX samples were very high in CHBr3, CHBr2Cl and CHBrCl2 concentrations with the CHBr3 concentrations being the highest. For this reason, the results in Table 84 are presented in micromoles (umoles) which permit comparison to the source water. The scrubber water sample after 21 days is close in concentration to the source water, which would indicate that the contact time with regenerated GAC was not long enough to remove any of the precursor. The THMMAX concentration in the quench tank is almost double that of the source water. It appears that

TABLE 84. THMMAX DATA[a] FROM MAY 13 AND 15, 1981 QUENCH AND SCRUBBER SAMPLES

	Source Water[b]	Scrubber 7 Day	Scrubber 14 Day	Scrubber 21 day
$CHCl_3$	1.00	0.02	0.03	0.03
$CHBrCl_2$	0.15	0.00	0.01	0.02
$CHBr_2Cl$	0.04	0.00	0.04	0.10
$CHBr_3$	0.00	0.00	0.29	1.09
THMMAX	1.19	0.02	0.37	1.24

	Source Water[a]	Quench 7 Day	Quench 14 Day
$CHCl_3$	1.00	0.09	0.14
$CHBrCl_2$	0.15	0.06	0.22
$CHBr_2Cl$	0.04	0.14	0.57
$CHBr_3$	0.00	0.67	1.39
THMMAX	1.19	0.96	2.32

[a] Concentrations expressed in µmoles/l.

[b] Mixture of SFEF and combined contactor effluents.

either additional THM precursor was being introduced (perhaps from the ash which is fractured off the GAC in the quench tank) or that there was a possible sample error. It is difficult to believe that any THM precursor could survive the regeneration temperatures. In any event, the THMMAX concentration observed in the quench and scrubber waters should not present any difficulty to a receiving stream.

The acid extract GC/FID profiles are presented in Figures 120 and 121. For the most part, the scrubber and quench water samples showed a reduction in the number and the magnitude of peaks. The May 15th scrubber sample (Figure 121) shows the presence of two peaks in the latter third of the chromatogram. These peaks have been observed in other acid extract GC/FID profiles so that their presence here was not alarming.

Other than unidentified and unquantified high chlorine demand, the parameters examined do not indicate the need for special disposal methods.

THMSIMDIST as a Surrogate for Distribution System THM Analyses

As previously described in Section 5, THMSIMDIST analyses of plant effluent water were performed as a surrogate for actual distribution system analyses. This afforded the opportunity to measure the effect of various treatment alternatives at the distal end of the distribution system. In Phase 1, the maximum travel time from treatment to consumption was estimated to be seven days. As a result of tracking fluoride through our distribution

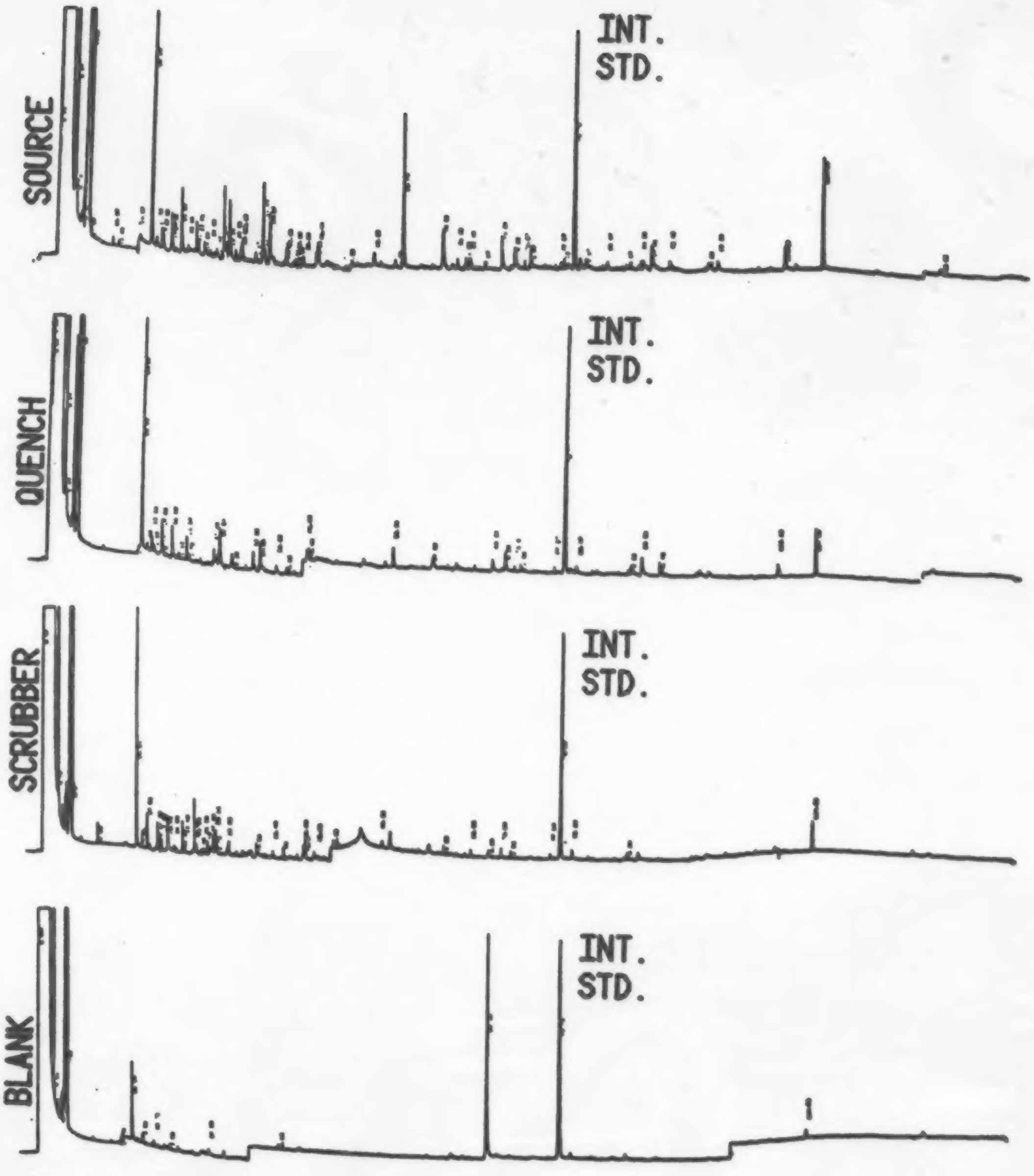


FIGURE 120. Acid extract profiles for quench and scrubber samples, May 13, 1981.

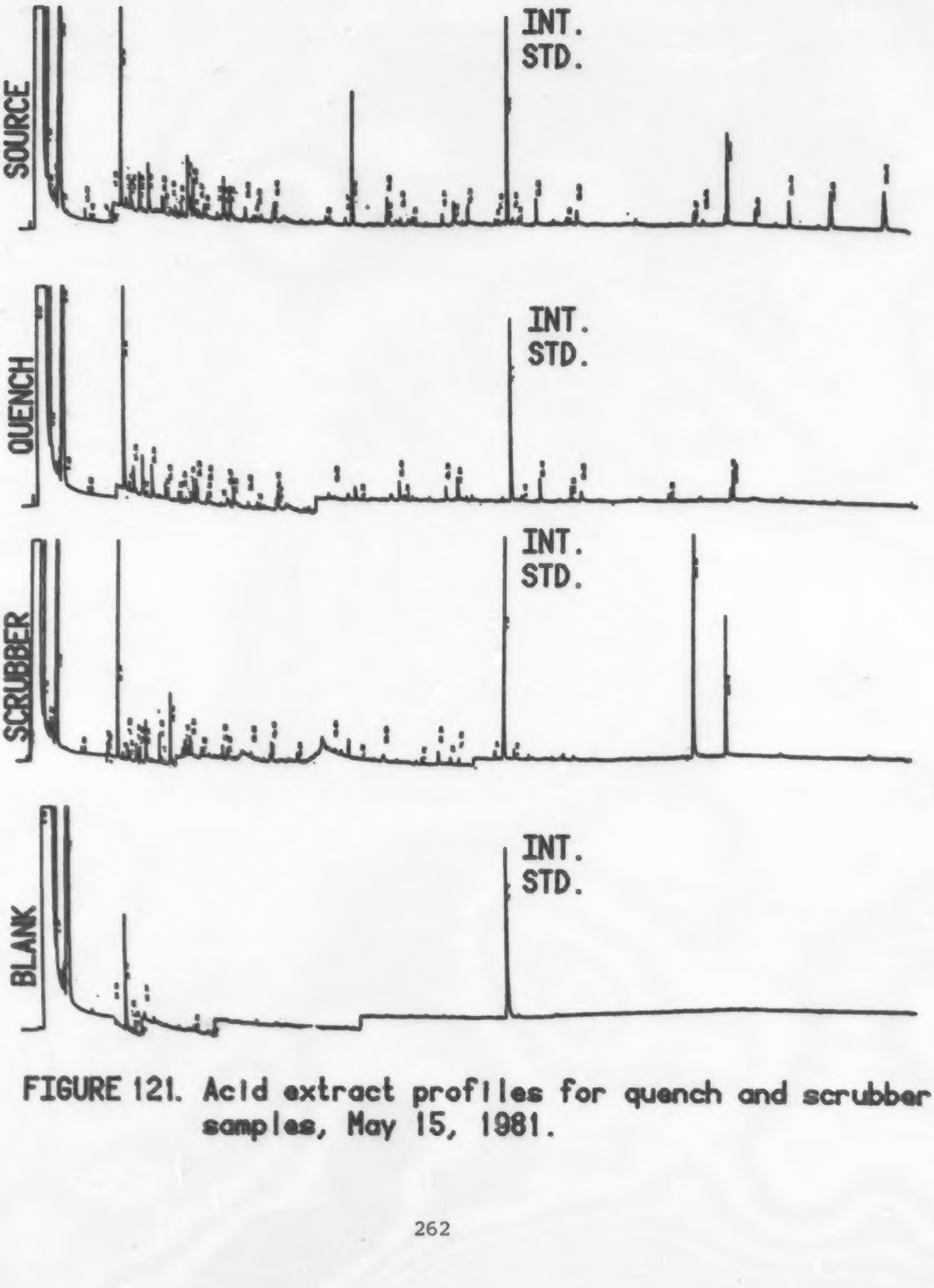


FIGURE 121. Acid extract profiles for quench and scrubber samples, May 15, 1981.

system in January, 1979, a more precise estimate was made of three days for this maximum travel time.

Figure 122 compares INSTTHM results from actual distribution system samples with three-day THMSIMDIST results from plant clearwell samples over the same time period. The figure demonstrates that three-day THMSIMDIST is a fairly reliable surrogate for distribution system THM analyses.

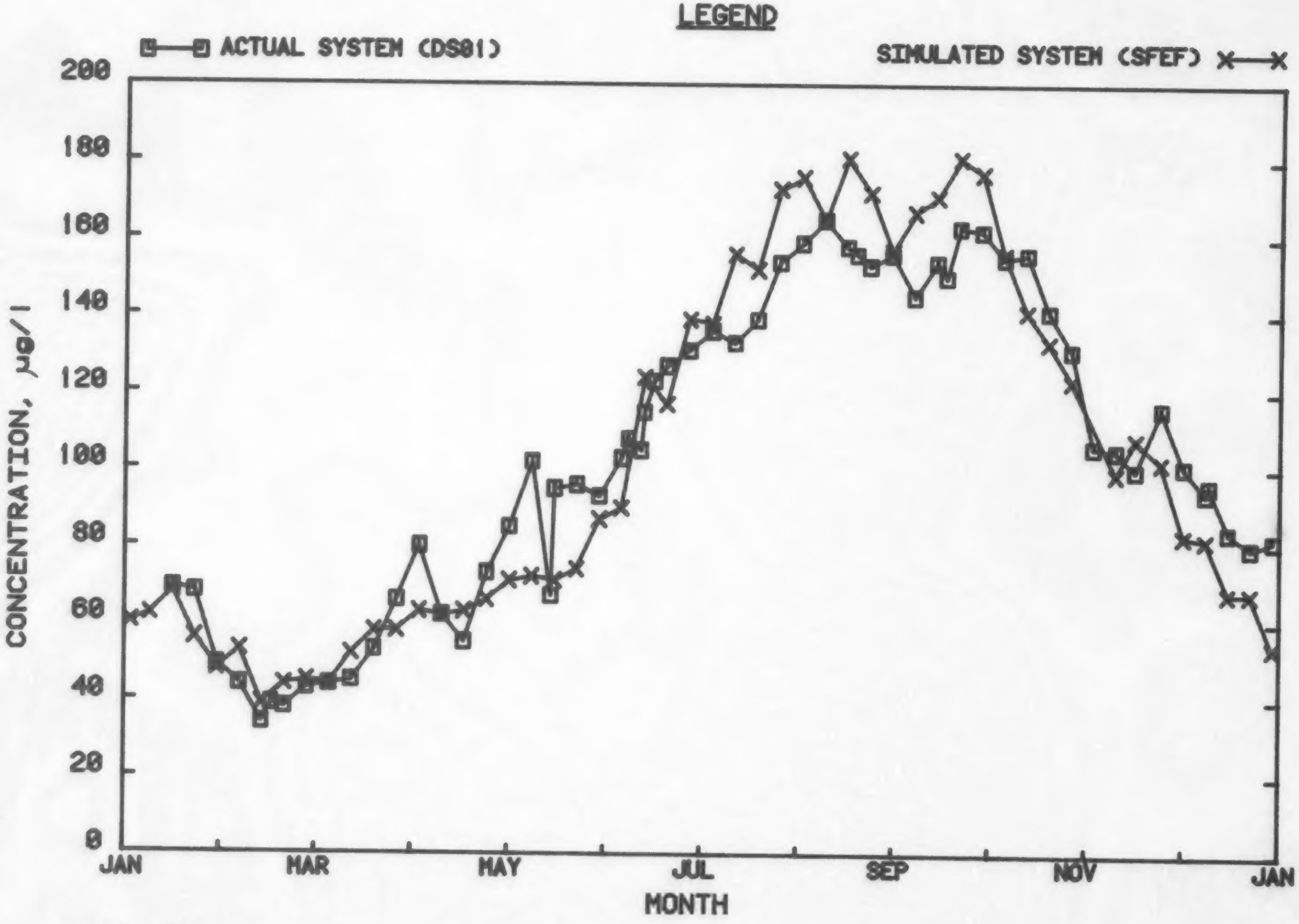


Figure 122. THM comparison of actual distribution system (ITTT) vs three-day simulated distribution system (STT3), 1980.

REFERENCES

1. U.S. Environmental Protection Agency, National Interim Primary Drinking Water Regulations. Federal Register, Vol. 40, No. 248, December 24, 1975.

2. U. S. Corps of Engineers. Ohio River Navigation, Past, Present, and Future. Department of Army, October, 1979.

3. Kinman, R. N. and J. Rickabaugh. In-Plant Modifications for Removal of Trace Organics from Cincinnati Drinking Water. University of Cincinnati, April 1, 1976.

4. Great Lakes--Upper Mississippi River Board of State Sanitary Engineers. Recommended Standards for Water Works. Health Education Service, Albany, N. Y., 1976.

5. U.S. Environmental Protection Agency, Process Design Manual for Carbon Adsorption. U.S. Environmental Protection Agency Technology Transfer, October, 1973. EPA 625/1-71-002a.

6. Symons, J. M. Interim Guide for the Control of Chloroform and Other Trihalomethanes. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976.

7. Public Law 93-523. Safe Drinking Water Act. 93rd Congress, S. 433, December 16, 1974.

8. DC-54 Ultralow Level Total Organic Carbon Analyzer System. Dohrmann, Division of Envirotech Corp., Santa Clara, Calif. 1st ed., May, 1977.

9. Stevens, A. A. and J. M. Symons. Measurement of Trihalomethane and Precursor Concentration Changes. Journal AWWA, October, 1977.

10. The Analysis of Trihalomethanes in Finished Water by the Purge and Trap Method. U.S. Environmental Protection Agency. Method 601, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio, September 9, 1977.

11. Eichelberger, J. W. and L. Littlefield. An Evaluation of the Finnigan Organics in Water Analyzer, U.S. Environmental Protection Agency, Cincinnati, Ohio.

12. Dressman, R. C., B. A. Najor and R. Redzikowski. The Analysis of Organohalides (OX) in Water as a Group Parameter. Proceedings AWWA Water Quality Technology Conference, Vol. II, Philadelphia, Pa, 1979. American Water Works Association, Denver, Colorado, 1980.

13. Grob, K. and G. Grob. Organic Substances in Potable Water and in its Precursor, Part II; Applications in the Area of Zurich. Journal Chromatography, 1974.

14. Grob, K. and F. Zurcher. Stripping of Trace Organic Substances from Water Equipment and Procedure. Journal Chromatography, Vol. 117, 1976.

15. Coleman, W. E., R. G. Melton, R. W. Slater, R. C. Kopfler, S. J. Voto, W. K. Allen and T. A. Aurand. Determination or Organic Contaminants by the Grob Closed-Loop-Stripping Technique. Proceedings of AWWA Water Quality Technology Conference, Vol. 2, Philadelphia, Pa, 1979. American Water Works Association, Denver, Colorado, 1980.

16. Sampling and Analyses Procedures for Screening of Industrial Effluents for Priority Pollutants. U.S. Environmental Protection Agency.

17. Methods for Organic Pesticides in Water and Wastewater. U.S. Environmental Protection Agency, 1971.

18. Standard Methods for the Examination of Water and Wastewater. 14th ed., 1976.

19. Federal Register, Vo. 42, No. 16, August 18, 1977.

20. Brunauer, Emmett, and Teller. Journal American Chemical Society, Vol. 60, 1938.

21. AWWA Standard for Granular Activated Carbon. American Water Works Association. AWWA B-604-74, 1st ed., January 28, 1974.

22. Modified Phenol Value Method. Westvaco Corp., November 1969.

23. Personal Communication with Mr. Boyd Jenson, Westvaco Corp.

24. Personnel communication with Mr. Rick Weatherly, Westvaco Corp., June, 1980.

25. Personal communication with ICI Americas, Inc., June, 1980.

26. Control of Organic Chemical Contaminants in Drinking Water. Federal Register, Vol. 43, No. 28, February 9, 1978.

27. Culp, Wesner and Culp. Estimating Water Treatment Costs, Vol. 2 - Cost Curves Applicable to 1 to 200 mgd Treatment Plants. EPA-60/2-79-162b, August, 1979.

APPENDIX A

COMPUTERIZED DATA DICTIONARY

F(#)	FIELD NAME	ABBR	VALUE	DESCRIPTION
F(1)	RUNDAY	DAY		DAY OF RUN
	CATEGORIES			
	NONE	NONE	-1	NO RUNDAY ASSOCIATED WITH THIS SAMPLE
F(2)	LOCATION	LOC	REQUIRED	SAMPLE LOCATION
	CATEGORIES (ONLY)			
	UNKNOWN	UNK	-1	UNKNOWN
	RAW	R	1	RAW
	SETTLED	SETT	2	SETTLED
	CLARIF	CLAR	3	CLARIFIED
	FILINF	FLIN	4	INFLUENT TO SAND AND GAC FILTERS
	CHAMBT	CT	5	CHAMBER T
	19-A-I	19A1	6	12 INCH DEPTH IN 18 INCH 12X40 MESH GAC FILTER
	19-A-II	19A2	7	18 INCH DEPTH IN 18 INCH 12X40 MESH GAC FILTER
	19-A-EFF	19AE	9	EFFLUENT OF 18 INCH 12X40 MESH GAC FILTER
	21-A-I	21A1	10	12 INCH DEPTH IN 30 INCH 12X40 MESH GAC FILTER
	21-A-II	21A2	11	18 INCH DEPTH IN 30 INCH 12X40 MESH GAC FILTER
	21-A-III	21A3	12	30 INCH DEPTH IN 30 INCH 12X40 MESH GAC FILTER
	21-A-EFF	21AE	13	EFFLUENT OF 30 INCH 12X40 MESH GAC FILTER
	23-A-I	23A1	14	12 INCH DEPTH IN 30 INCH 20X50 MESH GAC FILTER
	23-A-II	23A2	15	18 INCH DEPTH IN 30 ING 20X50 MESH GAC FILTER
	23-A-III	23A3	16	30 INCH DEPTH IN 30 INCH 20X50 MESH GAC FILTER
	23-A-EFF	23AE	17	EFFLUENT OF 30 INCH 20X50 MESH GAC FILTER
	MIDCLAR	MC	19	AFTER FLOC./BEFORE CLARIFICATION
	DISTR	DIS	22	DISTRIBUTION SYSTEM 6550 PARKLAND (PARKLAND & TWAIN)
	RV-1	RV1	23	COMMON INFLUENT TO REGENERATED/VIRGIN GAC FILT. ADS. COL.

F(#)	FIELD NAME	ABBR	VALUE	DESCRIPTION
	CATEGORIES (CONTINUED)			
	RV-2	RV2	24	15 INCH DEPTH IN 30 INCH-REGEN. GAC FILTER ADS. PILOT COL.
	RV-3	RV3	25	EFFLUENT OF 30 INCH-REGEN. GAC FILTER ADS. PILOT COL.
	RV-4	RV4	26	15 INCH DEPTH IN 30 INCH VIRGIN GAC FILTER ADS. PILOT COL.
	RV-5	RV5	27	EFFLUENT OF 30 INCH VIRGIN GAC FILTER ADSORBER PILOT COL.
	PFA-2	PFA2	29	3 FOOT DEPTH IN 15 FT. BITOM. GAC POST FILTER ADS. PILOT. COL. -3.2 MIN WVG
	PFA-3	PFA3	30	7 FOOT DEPTH IN 15 FT. BITOM. GAC POST FILTER ADS. PILOT COL. -7.5 MIN WVG
	PFA-4	PFA4	31	11 FOOT DEPTH IN 15 FT. BITUM. GAC POST FILTER ADS. PILOT COL. -11.8 MIN WVG
	PFA-5	PFA5	32	EFFLUENT OF 15 FT. VITUM. GAC POST FILTER ADS. PILOT COL. -16.02 MIN WVG
	PFA-6	PFA6	33	3 FOOT DEPTH IN 15 FT. LIGNITE GAC POST FILTER ADS. PILOT COL. -3.2 MIN ICI
	PFA-7	PFA7	34	7 FOOT DEPTH IN 15 FT. LIGNITE GAC POST FILTER ADS. PILOT COL. -7.5 MIN ICI
	PFA-8	PFA8	35	11 FOOT DEPTH IN 15 FT. LIGNITE GAC POST FILTER ADS. PILOT COL. -11.8 MIN ICI
	PFA-9	PFA9	36	EFFLUENT OF 15 FT. LIGNITE GAC POST FILTER ADS. PILOT COL. -16.02 MIN ICI
	B-EFF	BE	37	EFFLUENT OF 15 FOOT GAC CONTACTOR "A"
	SANDEFF	SFEF	39	SAND FILTER EFFLUENT
	A-7	A7	42	7 FOOT DEPTH IN 15 FOOT GAC CONTACTOR "A"
	A-9	A9	43	9 FOOT DEPTH IN 15 FOOT GAC CONTACTOR "A"
	A-11	A11	44	11 FOOT DEPTH IN 15 FOOT GAC CONTACTOR "A"
	A-EFF	AE	45	EFFLUENT OF 15 FOOT GAC CONTACTOR "A"
	B-4	B4	46	4 FOOT DEPTH IN 15 FOOT GAC CONTACTOR "B"
	B-7	B7	47	7 FOOT DEPTH IN 15 FOOT GAC CONTACTOR "B"
	B-9	B9	48	9 FOOT DEPTH IN 15 FOOT GAC CONTACTOR "B"
	PORTHOLE	PORT	40	FINISHED WATER TAKEN JUST AHEAD OF CLEARWELL AT PORTHOLE

F(#)	FIELD NAME	ABBR	VALUE	DESCRIPTION
	CATEGORIES (CONTINUED)			
	A-4	A4	41	4 FOOT DEPTH IN 15 FOOT GAC CONTRACTOR "A"
	C-7	C7	50	7 FOOT DEPTH IN 15 FOOT GAC CONTRACTOR "C"
	C-9	C9	51	9 FOOT DEPTH IN 15 FOOT GAC CONTRACTOR "C"
	C-EFF	CE	52	EFFLUENT OF 15 FOOT GAC CONTRACTOR "C"
	D-4	D4	53	4 FOOT DEPTH IN 15 FOOT GAC CONTRACTOR "D"
	D-7	D7	54	7 FOOT DEPTH IN 15 FOOT GAC CONTRACTOR "D"
	D-9	D9	55	9 FOOT DEPTH IN 15 FOOT GAC CONTRACTOR "D"
	D-11	D11	56	11 FOOT DEPTH IN 15 FOOT GAC CONTRACTOR "D"
	D-EFF	DE	57	EFFLUENT OF 15 FOOT GAC CONTRACTOR "D"
	C-4	C4	59	4 FOOT DEPTH IN 15 FOOT GAC CONTRACTOR "C"
	15-A-EFF	15AE	60	EFFLUENT OF 30 INCH 12X40 MESH GAC FILTER
	AIR	AIR	61	AIR REGENERATOR OFF GAS
	REGOV	ROV	62	REGENERATOR OUTLET VALVE
	SCRUB	SCRB	63	REGENERATOR AIR SCRUBBER EFFLUENT
	QUENCH	QNCH	64	REGENERATOR QUENCH TANK EFFLUENT
	SPENT	SPNT	65	REGENERATOR SPENT TANK EFFLUENT
	DISTR01	DS01	66	PARKLAND & TWAIN SAYLOR PARK
	DISTR02	DS02	67	EPA ST. CLAIR
	DISTR03	DS03	68	SPRINGFIELD & MARION
	DISTR04	DS04	69	EBENEZER & CLEVES-WARSAW
	DISTR05	DS05	70	GEST & STATE
	DISTR06	DS06	71	BEECHMONT AT ONTARIO
	DISTR07	DS07	72	QUEEN CITY & GRAND
	DISTR08	DS08	73	CHERRY GROVE TANK
	DISTR09	DS09	74	RIVERFRONT STADIUM
	DISTR10	DS10	75	WOOSTER PIKE
	DISTR11	DS11	76	GEST ST. SEWAGE
	DISTR12	DS12	77	5TH & CANTRAL
	DISTR13	DS13	78	4316 RIVER ROAD
	DISTR14	DS14	79	BRIDGETOWN & EBENEZER
	DISTR15	DS15	80	MAIN & CHURCH ST.
	DISTR16	DS16	81	W. 8TH & PEDRETTI
	DISTR17	DS17	82	KENWOOD & HUNT
	DISTR18	DS18	83	LUNKEN AIRPORT
	DISTR19	DS19	84	HARRISON AVE.
	DISTR20	DS20	85	WINTON & COMPTON
	DISTR21	DS21	86	MADISON & BROTHERTON
	DISTR22	DS22	87	MCMICKEN & VINE
	DISTR23	DS23	88	MONTGOMERY & MITCHELL FARM
	DISTR24	DS24	89	NORTHWOOD DR. & READING

F(#)	FIELD NAME	ABBR	VALUE	DESCRIPTION
	CATEGORIES (CONTINUED)			
	DISTR25	DS25	90	KEMPER (FOREST PARK)
	DISTR26	DS26	91	PERRY & KENWOOD
	DISTR27	DS27	92	MARKBREIT & EDWARDS
	DISTR28	DS28	93	MONTGOMERY & GALBRAITH
	DISTR29	DS29	94	ROUTE 8
	DISTR30	DS30	95	CLOUGH & 8 MILE
	DISTR31	DS31	96	1643 MARLOWE
	DISTR32	DS32	97	2729 ERIE
	DISTR33	DS33	98	MELISH & READING
	DISTR34	DS34	99	MIDWAY & GLENWAY
	DISTR35	DS35	100	MAIN STATION
	DISTR36	DS36	101	VINE & MAPLE
	DISTR37	DS37	102	VINE & SHEEHAN
	DISTR38	DS38	103	TENNYSON STATION
	DISTR39	DS39	104	VICTORY PKWY & TAFT
	DISTR40	DS40	105	HARRISON & JOHNSON
	DISTR41	DS41	106	SPRING GROVE & BARNARD
	DISTR42	DS42	107	LOVELAND MADEIRA ROAD
	DISTR44	DS44	108	2814 VINE ST.
	DISTR45	DS45	109	6005 MONTGOMERY
	DISTR46	DS46	110	4033 GLENWAY
	DISTR47	DS47	111	3600 BANNING
	DISTR48	DS48	112	9763 COLERAIN
	DISTR49	DS49	113	8210 PIPPIN
	DISTR50	DS50	114	10035 MONTGOMERY
	DISTR51	DS51	115	4700 BLUE ROCK
	15-A-INF	15AI	116	15 A INF
	BB-4	BB4	117	4 FOOT DEPTH IN 15 FOOT GAC CONTACTOR "BB"
	BB-7	BB7	118	7 FOOT DEPTH IN 15 FOOT GAC CONTACTOR "BB"
	BB-EFF	BBE	119	EFFLUENT OF 15 FOOT GAC CONTACTOR "BB"
	DISTR52	DS52	120	7206 HARRISON
	DISTR53	DS53	121	6926 HARRISON
	DISTR54	DS54	122	6597 SPRINGDALE
	DISTR55	DS55	123	6950 RIPPLE
	DISTR56	DS56	124	205 CALHOUN
	DISTR57	DS57	125	3100 READING
	15AE-P	15AP	126	FILTER 15A-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION PRIOR TO BEING PLACED INTO SERVICE
	15AE-S	15AS	127	FILTER 15A-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION AFTER BEING TAKEN OUT OF SERVICE (SPENT).
	15AE-R	15AR	128	FILTER 15A-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION AFTER REGENERATION
	21AE-P	21AP	129	FILTER 21A-EFF CARBON SAMPLE

F(#)	FIELD NAME	ABBR	VALUE	DESCRIPTION
	CATEGORIES (CONTINUED)			
				REPRESENTATIVE OF CARBON CONDITION PRIOR TO BEING PLACED INTO SERVICE.
	21AE-S	21AS	130	FILTER 21A-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION AFTER BEING TAKEN OUT OF SERVICE (SPENT).
	21AE-R	21AR	131	FILTER 21A-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION AFTER REGENERATION.
	A-EFF-P	AP	132	CONTACTOR A-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION PRIOR TO BEING PLACED INTO SERVICE.
	A-EFF-S	AS	133	CONTACTOR A-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION AFTER BIENG TAKEN OUT OF SERVICE (SPENT).
	A-EFF-R	AR	134	CONTACTOR A-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION AFTER REGENERATION.
	BB-EFF-P	BBP	135	CONTACTOR BB-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION PRIOR TO BEING PLACED INTO SERVICE.
	BB-EFF-S	BBS	136	CONTACTOR BB-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION AFTER BEING TAKEN OUT OF SERVICE (SPENT).
	BB-EFF-R	BBR	137	CONTACTOR BB-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION AFTER REGENERATION.
	C-EFF-P	CP	138	CONTACTOR C-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION PRIOR TO BEING PLACED INTO SERVICE.
	C-EFF-S	CS	139	CONTACTOR C-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION AFTER BEING TAKEN OUT OF SERVICE (SPENT).
	C-EFF-R	CR	140	CONTACTOR C-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION AFTER REGENERATION.
	D-EFF-P	DP	141	CONTACTOR D-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION PRIOR TO BEING PLACED INTO SERVICE.
	D-EFF-S	DS	142	CONTACTOR D-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION AFTER BEING TAKEN OUT OF SERVICE (SPENT).

F(#)	FIELD NAME	ABBR	VALUE	DESCRIPTION
	CATEGORIES (CONTINUED)			
	D-EFF-R	DR	143	CONTACTOR D-EFF CARBON SAMPLE REPRESENTATIVE OF CARBON CONDITION AFTER REGENERATION.
	CONEFF	CNEF	144	THE COMBINED EFFLUENT FROM THE CARBON CONTACTORS WHICH ARE ON-LINE AT THE TIME OF THE SAMPLE COLLECTION
	DISTR58	DS58	145	LIBERTY AND LINN
	DISTR59	DS59	146	SALEM AND SUTTON
	DISTR60	DS60	147	LINWOOD AND DELTA
	CONTFILT	COFL	148	MIXTURE OF SAN FILTER EFFLUENT AND COMBINED CONTACTOR EFFLUENTS FROM THE CONTACTORS WHICH WERE ON-LINE AT THE TIME OF SAMPLE COLLECTION.
	BNMTBLNK	BNMB	149	BASE NEUTRAL METHOD BLANK.
	BNSOBLNK	BNSB	150	BASE NEUTRAL SOLVENT BLANK.
F(3)	PARAMETER	PARM	REQUIRED	PARAMETER REPORTED
	CATEGORIES (ONLY)			
	UNKNOWN	UNK	-1	UNKNOWN
	ODOR	ODOR	1	(TON) UNITS - THRESHOLD ODOR NUMBER
	BENZENE	BENZ	2	μG/L, BENZENE INSTANTANEOUS READING
	XYLENE	XYLE	3	μG/L, XYLENE INSTANTANEOUS READING
	ETLBNZ	EBEN	4	μG/L, ETHYLBENZENE, INSTANTANEOUS READING
	TOLUENE	TOLU	5	μG/L, TOLUENE INSTANTANEOUS READING
	HEXANE	HEX	6	μG/L, HEXANE INSTANTANEOUS READING
	TETRALIN	TETL	7	μG/L, TETRALIN INSTANTANEOUS READING
	CLCOMBD	CLCO	8	MG/L, CHLORINE-COMBINED INITIAL, INSTANTANEOUS READING, DPD

F(0)	FIELD NAME	ABBR	VALUE	DESCRIPTION
	CATEGORIES (CONTINUED)			
	CLFREEA	CLFR	9	MG/L. CHLORINE - FREE INITIAL, FREE RESIDUAL-AMPEROMETRIC
	CLTOTALA	CLTO	10	MG/L, CHLORINE - TOTAL TOTAL CHLORINE RESIDUAL-AMPEROMETRIC
	SPC	PCNT	11	CTS/ML, PLATE COUNT, STANDARD INSTANTANEOUS READING
	PH	PH	12	INITIAL PH SAMPLE
	PURGOC	POC	13	UG/L, PURGEABLE ORGANIC CARBON INSTANTANEOUS READING-DOHRMAN
	TOC	TOC	14	MG/L, TOTAL ORGANIC CARBON
	TEMPSAMP	TEMP	15	TEMPERATURE OF SAMPLE (C)
	TOT.COLI	TCOL	16	TOTAL COLIFORMS - COUNTS/100 ML
	TOTALSOL	TSOL	17	MG/L, TOTAL SOLIDS
	TFILSOL	TSF	18	MG/L, TOTAL FILTERED SOLIDS
	TURB	TURB	19	NTU-NEPHELOMETRIC TURBIDITY UNITS
	NPOC	NPOC	20	UG/L, NONPURGEABLE ORGANIC CARBON INSTANTANEOUS READING
	DO2	DO	21	MG/L, DISSOLVED OXYGEN INSTANTANEOUS READING
	TC7TTHM	MTTT	22	UG/L, TRIHALOMETHANE TERMINAL READING, STORED 7 DAYS, CHLORINE, TEMP=85F(28.5C), PH=9.5
	TC7CL3F	MCLR	23	UG/L, CHLOROFORM TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(28.5C), PH=9.5
	TC7BR3F	MCH3	24	UG/L, BROMOFORM TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(28.5C), PH=9.5
	TC7BR1F	MCL2	25	UG/L BROMODICHLOROMETHANE, TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(28.5C), PH=9.5
	TC7BR2F	MCB2	26	UG/L, CHLORODIBROMOMETHANE, TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(28.5C), PH=9.5
	TC7CCL4F	MCL4	27	UG/L, CARBON TETRACHLORIDE, TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(28.5C), PH=9.5
	TC7CL3EF	M3C3	29	UG/L, TRICHLOROETHANE-1,1,1 TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP-85F(29-30C), PH=9.5
	TC7DCMAF	MDIC	30	UG/L, DICHLOROMETHANE TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(29-30C), PH=9.5
	TC7CL4E	MC4E	31	UG/L, TETRACHLOROETHANE-1,1,2,2 TERMINAL READING, STORED 7 DAYS, CHLORINE, TEMP=85F(29-30C), PH=9.5
	TC7TRCE	MET3	32	UG/L, TRICHLOROETHENE TERMINAL

F(#)	FIELD NAME	ABBR	VALUE	DESCRIPTION
	CATEGORIES (CONTINUED)			
				READING, STORED 7 DAYS, CHLORINE, TEMP=85F(29-30C), PH=9.5
	TC7ODBF	MB22	33	UG/L, DICHLOROBENZENE-ORTHO TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(29-30C), PH=9.5
	TC7CLBZF	MBN2	35	UG/L, CHLOROBENZENE TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(29-30C), PH=9.5
	TR3TTHMF	STT3	36	UG/L, TRIHALOMETHANE, TERMINAL READING, STORED 3 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=8.2, ALL PHASES BUT 1-0, 2-0, 2-1 AND 2-2
	TR3CL3F	SCL3	37	UG/L, CHLOROFORM, TERMINAL READING, STORED 3 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=AMBIENT, ALL PHASES BUT 1-0, 2-0, 2-1 AND 2-2
	TR3BR3F	SB33	38	UG/L, BROMOFORM, TERMINAL READING, STORED 3 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=AMBIENT, ALL PHASES BUT 1-0, 2-0, 2-1 AND 2-2
	TR3BR1F	SB13	39	UG/L, BROMODICHLOROMETHANE, TERMINAL READING, STORED 3 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=AMBIENT, ALL PHASES BUT 1-0, 2-0, 2-1 AND 2-2
	TR3BR2F	SB23	40	UG/L, CHLORODIBROMOMETHANE, TERMINAL READING, STORED 3 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=AMBIENT, ALL PHASES BUT 1-0, 2-0, 2-1 AND 2-2
	TR7CCL4F	SCL4	41	UG/L, CARBON TETRACHLORIDE, TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=AMBIENT, PHASES 1-0 AND 2-0 ONLY
	TR7CL3EF	S3C3	43	UG/L, TRICHLOROETHANE-1,1,1 TERMINAL READING STORED 7 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=AMBIENT, PHASES 1-0 AND 2-0 ONLY
	TR7DCMMF	SDIC	44	UG/L, DICHLOROMETHANE TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=AMBIENT, PHASES 1-0 AND 2-0 ONLY
	TR7CL4EF	SC4E	45	UG/L, TETRACHLOROETHANE-1,1,2,2 TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=AMBIENT,

F(0)	FIELD NAME	ABBR	VALUE	DESCRIPTION
	CATEGORIES (CONTINUED)			
				PH=AMBIENT, PHASES 1-0 AND 2-0 ONLY
	TR7TRCEF	SET3	46	UG/L, TRICHLOROETHENE TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=AMBIENT, PHASES 1-0 AND 2-0 ONLY
	TR7ODCBF	SBZ2	47	UG/L, DICHLOROBENZENE-ORTHO TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=AMBIENT, PHASES 1-0 AND 2-0 ONLY
	TR7CLBZF	SBNZ	49	UG/L, CHLOROBENZENE TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=AMBIENT, PHASES 1-0 AND 2-0 ONLY
	FP7TTHMF	FTTT	50	UG/L, TRIHALOMATHANE FORMATION POTENTIAL, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(29-30C), PH=9.5
	FP7CL3F	FCLR	51	UG/L, CHLOROFORM FORMATION POTENTIAL, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(29-30C), PH=9.5
	FP7BR3F	FCH3	52	UG/L, BROMOFORM FORMATION POTENTIAL, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(29-30C), PH=9.5
	FP7BR1F	FCL2	53	UG/L, BROMODICHLOROMETHANE FORMATION POTENTIAL, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(29-30C), PH=9.5
	FP7BR2F	FCB2	54	UG/L, CHLORODIBROMOMETHANE FORMATION POTENTIAL, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(29-30C), PH=9.5
	FP7CCL4F	FCL4	55	UG/L, CARBON TETRACHLORIDE FORMATION POTENTIAL, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(29-30C), PH=9.5
	FP7CL3EF	F3C3	57	UG/L, TRICHLOROETHANE-1,1,1 FORMATION POTENTIAL, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(29-30C), PH=9.5
	FP7DCMAF	FDIC	58	UG/L, DICHLOROMETHANE FORMATION POTENTIAL, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(29-30C), PH=9.5
	FP7CL4EF	FC4E	59	UG/L, TETRACHLOROETHANE-1,1,2,2 FORMATION POTENTIAL, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(29-30C), PH=9.5
	FPTRCEEN	FET3	60	UG/L, TRICHLOROETHENE FORMATION POTENTIAL, STORED 7 DAYS, FREE

F(#)	FIELD NAME	ABBR	VALUE	DESCRIPTION
	CATEGORIES (CONTINUED)			
				CHLORINE, TEMP=85F(29-30C), PH=9.5
	FP7ODCBF	FB22	61	UG/L, DICHLOROBENZENE-ORTHO FORMATION POTENTIAL, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(29-30C)M PH=9.5
	FP7CLBNZ	FBNZ	63	UG/L, CHLOROBENZENE FORMATION POTENTIAL, STORED 7 DAYS, FREE CHLORINE, TEMP=85F(29-30C), PH=9.5
	TTHM	ITTT	68	UG/L, TRIHALOMETHANE INSTANTANEOUS READING, SUM OF FOUR TRIHALOMETHANE READINGS
	CHLROFRM	ICLR	69	UG/L, CHLOROFORM INSTANTANEOUS READING
	BROMOFRM	ICH3	70	UG/L, BROMOFORM INSTANTANEOUS READING
	BRDCLMET	ICL2	71	UG/L, BROMODICHLOROMETHANE INSTANTANEOUS READING
	CLDBRMET	ICB2	72	UG/L, CHLORODIBROMOMETHANE INSTANTANEOUS READING
	CARBTET	ICL4	73	UG/L, CARBON TETRACHLORIDE INSTANTANEOUS READING
	DCETAN	ICC2	74	UG/L, DICHLOROETHANE-1,2 INSTANTANEOUS READING
	TRCETAN	I3C3	75	UG/L, TRICHLOROETHANE-1,1,1 (ALSO METHYL CHLOROFORM) INSTANTANEOUS READING
	DCLMETAN	IDIC	76	UG/L, DICHLOROMETHANE INSTANTANEOUS READING
	TCLRETAN	IC4E	77	UG/L, TETRACHLOROETHENE-1,1,2,2 INSTANTANEOUS READING
	TRCETEN	IET3	78	UG/L, TRICHLOROETHENE (ALSO TRICHLOROETHYLENE) INSTANTANEOUS READING
	ODICLBNZ	IB22	79	UG/L, DICHLOROBENZENE-ORTHO INSTANTANEOUS READING
	CLRBNZ	IBNZ	81	UG/L, CHLOROBENZENE INSTANTANEOUS READING
	SUMFLOTG	SFLO	91	SUMMATION FLOW IN 1000 US GALLONS
	DELFLOTG	DFLO	92	DELTA FLOW IN 1000 US GALLONS,
	BED.VOL	BVOL	93	FILTER BED VOLUME IN US GALLONS
	CARBWTPD	C	94	CARBON WEIGHT IN THE FILTER, POUNDS
	TH3PH	SPH	82	PH OF SAMPLE STORED FOR THM ANALYSIS, STORED 3 DAYS
	TC7PH	FPPH	83	PH OR SAMPLE STORED FOR THM ANALYSIS, STORED 7 DAYS
	CLSDF	SCLF	84	CHLORINE-FREE, FROM SIMULATED DISTRIBUTION SYSTEM
	FP3TTHMF	FCLF	85	UG/L, TRIHALOMETHANE, FORMATION POTENTIAL, STORED 3 DAYS, FREE CHLORINE, TEMP=85F(29-30C), PH=9.5
	ODORDCL	ODDC	95	TON-UNITS-THRESHOLD ODOR

F(#)	FIELD NAME	ABBR	VALUE	DESCRIPTION
	CATEGORIES (CONTINUED)			
				NUMBER-DECHLORINATED
	TOX	TOCL	96	TOTAL ORGANIC HALOGENS
	NHUNK	NUNK	97	PURGEABLE, NONHALOGENATED, COMPOUND UNKNOWN
	NPCL	NPCL	98	µG/L, NONPURGEABLE ORGANIC CHLORINE INSTANTANEOUS READING
	ISOPHORO	ISOP	99	µG/L, ISOPHORONE INSTANTANEOUS READING
	NPTHALEN	NAPH	100	µG/L, NAPHTHALENE INSTANTANEOUS READING (PAH)
	B2ETLHPH	BEHP	101	µG/L, BIS(2-ETHYL HEXYL) PHTHALATE INSTANTANEOUS READING
	BTBZPHTH	BBPL	102	µG/L, BUTYL BENZYL PHTHALATE INSTANTANEOUS READING
	DNBLPHTH	DNBP	103	µG/L, DI-N-BUTYL PHTHALATE INSTANTANEOUS READING
	DMELPHTH	DMPL	104	µG/L, DIMETHYL PHTHALATE INSTANTANEOUS READING
	NITROBNZ	NBNZ	105	µG/L, NITROBENZENE INSTANTANEOUS READING
	24DNITOL	4DNT	106	µG/L DINITROTOLUENE 2,4 INSTANTANEOUS READING
	26DNITOL	6DNT	107	µG/L, DINITROTOLUENE 2,6 INSTANTANEOUS READING
	BENZIDIN	BNDI	108	µG/L, BENZIDINE INSTANTANEOUS READING
	DCLBSZDN	DCBI	109	µG/L, DICHLOROBENZIDINE-3,3 INSTANTANEOUS READING
	ANILINE	ANIL	110	µG/L, ANILINE INSTANTANEOUS READING
	ONAPTHYL	ONAP	111	µG/L, NAPHTHYLAMINE-ORTHO INSTANTANEOUS READING (PAH)
	PYRIDINE	PYRI	112	µG/L, PYRIDINE, INSTANTANEOUS READING
	OPICLINE	OPIC	113	µG/L, OPICLINE INSTANTANEOUS READING
	24MELPYR	2DIM	114	µG/L, DIMETHYL PYRENE-2,4 INSTANTANEOUS READING (PAH)
	DETLPHTH	DEPL	115	µG/L, DIETHYL PHTHALATE INSTANTANEOUS READING
	DIBLPHTH	DIBP	116	µG/L, DI-ISOBUTYL PHTHALATE INSTANTANEOUS READING
	DOTLPHTH	DOPL	117	µG/L, DI-NOCTYL PHTHALATE INSTANTANEOUS READING
	NBTISOPH	BUTI	118	µG/L, N-BUTYL ISOBUTYL PHTHALATE INSTANTANEOUS READING
	TTHMUNK	TUNK	120	µG/L, TRIHALOMETHANE INSTANTANEOUS ANALYSIS, COMPOUND UNKNOWN
	CARBNTVP	CWAP	121	CARBON WEIGHT VOLUME IN POUNDS
	SUMFLOWG	SFLM	122	SUMMATION FLOW IN MILLION GALLONS
	TOT	TOT	123	FOR CALC PROGRAM
	DIF	DIF	125	FOR CALC PROGRAM

F(#)	FIELD NAME	ABBR	VALUE	DESCRIPTION
	CATEGORIES (CONTINUED)			
	DIF2	DIF2	126	FOR CALC PROGRAM
	TOT2	TOT2	124	FOR CALC PROGRAM
	CARBWTVK	CWVK	127	CARBON WEIGHT VOLUMN IN KILOGRAMS
	IODINE1	IOD1	128	IODINE NUMBER IN MG/G PERFORMED ON CARBON SAMPLE EXTRACTED BETWEEN THE HOURS OF 6AM AND 2PM
	IODINE2	IOD2	129	IODINE NUMBER IN MG/G PERFORMED ON CARBON SAMPLE EXTRACTED BETWEEN THE HOURS OF 2PM AND 10PM
	IODINE3	IOD3	130	IODINE NUMBER IN MG/G PERFORMED ON CARBON SAMPLE EXTRACTED BETWEEN THE HOURS OF 10PM AND 6AM
	APP.DEN1	AD1	131	APPARENT DENSITY IN LBS./CU. FT. PERFORMED ON CARBON SAMPLE EXTRACTED BETWEEN THE HOURS OF 6AM AND 2PM
	APP.DEN2	AD2	132	APPARENT DENSITY IN LBS./CU. FT. PERFORMED ON CARBON SAMPLE EXTRACTED BETWEEN THE HOURS OF 2PM AND 10PM
	APP.DEN3	AD3	133	APPARENT DENSITY IN LBS/CU. FT. PERFORMED ON CARBON SAMPLE EXTRACTED BETWEEN THE HOURS OF 10PM AND 6AM
	RB.TEMP1	RBT1	134	REGENERATOR BED TEMPERTURE IN DEG. FAHRENHEIT PERFORMED ON CARBON SAMPLE EXTRACTED BETWEEN THE HOURS OF 6AM AND 2PM
	RB.TEMP2	RBT2	135	REGENERATOR BED TEMPERATURE IN DEG. FAHRENHEIT PERFORMED ON CARBON SAMPLE EXTRACTED BETWEEN THE HOURS OF 2PM AND 10PM
	RB.TEMP3	RBT3	136	REGENERATOR BED TEMPERATURE IN DEG. FAHRENHEIT PERFORMED ON CARBON SAMPLE EXTRACTED BETWEEN THE HOURS OF 10PM AND 6AM
	CAOX	CAOX	137	CARBON ADSORBABLE ORGANOHALIDES. CONCENTRATION EXPRESS IN UG/L AS CHLORIDES.
	TA7TTHMF	STT7	138	UG/L, TRIHALOMETHANE, TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=8.2, PHASES 1-0, 2-0, 2-1 AND 2-2
	TA7CL3F	SCL7	139	UG/L, CHLOROFORM, TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=AMBIENT, PHASES 1-0, 2-0, 2-1 AND 2-2
	TA7BR3F	SB37	140	UG/L, BROMOFORM, TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=AMBIENT, PHASES

F(#)	FIELD NAME	ABBR	VALUE	DESCRIPTION
	CATEGORIES (CONTINUED)			
				1-0, 2-0, 2-1, AND 2-2
	TA7BR1F	SB17	141	µG/L, BROMODICHLOROMETHANE, TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=AMBIENT, PHASES 1-0, 2-0, 2-1 AND 2-2
	TA7BR2F	SB27	142	µG/L, CHLORODIBROMOMETHANE, TERMINAL READING, STORED 7 DAYS, FREE CHLORINE, TEMP=AMBIENT, PH=AMBIENT, PHASES 1-0, 2-0, 2-1 AND 2-2
	TA7PH	SPH7	143	PH OF SAMPLE STORED FOR THM ANALYSIS, STORED 7 DAYS
	TRMETYPN	TRMP	144	NG/L TRIMETHYL - 1 - PENTENE - 2, 2, 4 INSTANTANEOUS READING
	DMETBZ34	DM34	145	NG/L DIMETHYLBENZENE - 1, 3 AND 1, 4 INSTANTANEOUS READING
	DMETBZ2	DMB2	146	NG/L DIMETHYLBENZENE - 1, 2 INSTANTANEOUS READING
	PRPYLBNZ	PPBZ	147	NG/L PROPYLBENZENE INSTANTANEOUS READING
	METYBZE4	MBE4	148	NG/L METHYLBENZENE - 1 - ETHYL - 4 INSTANTANEOUS READING
	METYBZE2	MBE2	149	NG/L METHYLBENZENE - 1 - ETHYL - 2 INSTANTANEOUS READING
	TRMETBNZ	TRMB	150	NG/L TRIMETHYLBENZENE 1, 2, 4 INSTANTANEOUS READING
	14DICLBZ	DCB4	151	NG/L DICHLOROBENZENE - 1, 4 INSTANTANEOUS READING
	12DICLBZ	DCB2	152	NG/L DICHLOROBENZENE - 1, 2 INSTANTANEOUS READING
	HCLRETAN	HCLE	153	NG/L HEXACHLOROETHANE INSTANTANEOUS READING
	NONANAL	NNAL	154	NG/L NONANAL INSTANTANEOUS READING
	TMETYBNZ	TMBZ	155	NG/L TETRAMETHYLBENZENE - 1, 2, 3, 5 INSTANTANEOUS READING
	TRCLRBNZ	TRCB	156	NG/L TRICHLOROBENZENE INSTANTANEOUS READING
	DECANAL	DECL	157	NG/L DECANAL INSTANTANEOUS READING
	UNDECANL	UDCL	158	NG/L UNDECANAL INSTANTANEOUS READING
	METYNAPH	MTNP	159	NG/L METHYLNAPHTALENE INSTANTANEOUS READING
	12DPYHYD	DPHY	160	NG/L DIPHENYLHYDRAZINE INSTANTANEOUS READING
	ANAPTHYL	ANAP	161	µG/L, NAPHTHYLAMINE-ALPHA, INSTANTANEOUS READING
	APICLINE	APIC	162	µG/L, PICOLINE-ALPHA, INSTANTANEOUS READING
	BNEUNK	BUNK	163	µG/L, BASE NEUTRAL EXTRACTABLE ANALYSIS, COMPOUND UNKNOWN

F(#)	FIELD NAME	ABBR	VALUE	DESCRIPTION
F(4)	READING	AMT		READING
	CATEGORIES			
	+	+	-1	NOT ENTERED
	UNKNOWN	UNK	-1	NOT ENTERED
F(5)	NOTE	N		STANDARD NOTE CODE
	CATEGORIES			
	NONE	NONE	-1	NONE
	100	100	100	DUPLICATE ANALYSIS (TWO SUCCESSIVE ANALYSIS OF SAMPLE ON SAME DAY)
	200	200	200	REPLICATE ANALYSIS (ANALYSIS OF SAMPLE ON TWO DIFFERENT DAYS)
	300	300	300	SAMPLE OR ANALYSIS ERROR. DATA MAY NOT BE VALID. IF NO CONCENTRTION OBTAINED ENTER 999999 IN READING FIELD.
	400	400	400	PROBABLE BOLTON PLANT WATER
	500	500	500	CONTROL SAMPLE (TWO SEPARATE FORMATION POTENTIALS SET UP & ANALYZED ON SAME DAY)
	600	600	600	SAMPLE DECHLORINATED BEFORE ODOR ANALYSIS
	700	700	700	VALUE RECORDED IS A NEGATIVE VALUE-SHOULD BE PRECEDED BY MINUS SIGN
	800	800	800	SAMPLE NOT TAKEN
	900	900	900	ARTIFACT
	950	950	950	1 LITER PURGE
	330	330	330	THIS DATUM WAS DEVELOPED BY OUTSIDE CONTRACT LABORATORIES. THE INCONSISTENCY OF RESULTS TENDS TO INDICATE THAT CAUTION SHOULD BE USED IN INTERPRETATION.
	331	331	331	THIS DUPLICATE DATUM WAS DEVELOPED BY OUTSIDE CONTRACT LABORATORIES. THE INCONSISTENCY OF RESULTS TENDS TO INDICATE THAT CAUTION SHOULD BE USED IN INTERPRETATION.
	332	332	332	THIS REPLICATE DATUM WAS DEVELOPED BY OUTSIDE CONTRACT LABORATORIES.

F(#)	FIELD NAME	ABBR	VALUE	DESCRIPTION
	CATEGORIES (CONTINUED)			
				THE INCONSISTENCY OF RESULTS TENDS TO INDICATE THAT CAUTION SHOULD BE USED IN INTERPRETATION.
F(6)	NOTE2	N2		NOTE2
	CATEGORIES (ONLY)			
	NONE	NONE	-1	NONE
	001	001	1	PRESENT BELOW 0.1 PPB=NR. ENTER 0.0 IN READING FIELD.
	002	002	2	NOT DETECTED. ENTER 0.0 IN READING FIELD.
	003	003	3	PRESENT IN THE RANGE OF 0.1 TO 0.4 PPB. ENTER 0.2 IN READING FIELD.
	004	004	4	LESS THAN 1 (<1). INTENDED FOR BACTERIA ONLY. ENTER 0.0 IN READING FIELD.
	005	005	5	HIGH BACKGROUND (GREATER THAN 200 COLONIES). INTENDED FOR TOTAL COLIFORM ONLY. ENTER 300 IN NOTE FIELD AND COUNT IN READING FIELD.
	006	006	6	LESS THAN 1 (<1) TOTAL COLIFORM, HIGH BACKGROUND (GREATER THAN 200 COLONIES). ENTER 300 IN NOTE FIELD AND 999999 IN READING FIELD.
	007	007	7	VALUE RECORDED IS A NEGATIVE VALUE
	0	0	-1	NONE
	030	030	30	BALSAMIC (FLOWERY) SWEETISH
	031	031	31	CHEMICAL
	032	032	32	CHEMICAL HYDROCARBON
	033	033	33	CHEMICAL, CHLORINOUS
	034	034	34	AROMATIC (SPICEY)
	035	035	35	DISAGREEABLE
	036	036	36	DISAGREEABLE (FISHY)
	037	037	37	DISAGREEABLE (SEPTIC)
	038	038	38	EARTHY
	039	039	39	GRASSY
	040	040	40	MUSTY
	041	041	41	MUSTY, MOLDY
	042	042	42	VEGETABLE
	050	050	50	BASED ON ACTUAL DELIVERED WEIGHTS, NOT ON VOLUME X APPARENT DENSITY
	051	051	51	BASED ON VOLUME X APPARENT DENSITY OF 30.5 LBS./CU. FT.
	053	053	53	FLOWS BASED ON INTERPOLATIONS OF METERED FLOWS
	052	052	52	FLOWS BASED ON AVERAGE OF 5 MGD
	060	060	60	PHASE 1-0 FILTERS WERE DOWN FOR FOUR DAYS. DATE IN THIS RECORD IS FOUR DAYS LATER THAN ACTUAL SAMPLE DATE.
	055	055	55	ANALYSIS RUN BY GEORGIA TECH.

F(#)	FIELD NAME	ABBR	VALUE	DESCRIPTION
	CATEGORIES (CONTINUED)			
				ENGINEERING EXPERIMENTAL STATION.
	070	70	70	PRESENT BELOW 3 PPB. ENTER 1.5 IN READING FIELD.
	080	80	80	COMPOUND NOT IDENTIFIED. CONCENTRATION NOT OBTAINABLE. ENTER 999999 IN READING FIELD.
F(7)	UNK. RET	U.R		UNK. RET
F(8)	PHASE	RUN		PHASE OR RUN
	CATEGORIES (ONLY)			
	NONE	NONE	-1	NO PHASE
	1-0	1-0	1	PHASE 1, RUN 0. GAC SYSTEM CONTAINS VIRGIN GAC
	1-1	1-1	2	PHASE 1, RUN 1. GAC SYSTEM CONTAINS ONCE REGENERATED GAC
	2-0	2-0	3	PHASE 2, RUN 0. GAC SYSTEM CONTAINS VIRGIN GAC
	2-1	2-1	4	PHASE 2, RUN 1. GAC SYSTEM CONTAINS ONCE REGENERATED GAC
	2-2	2-2	5	PHASE 2, RUN 2. GAC SYSTEM CONTAINS TWICE REGENERATED GAC
	3-0	3-0	6	PHASE 3, RUN 0. GAC SYSTEM CONTAINS VIRGIN GAC
	3-1	3-1	7	PHASE 3, RUN 1. GAC SYSTEM CONTAINS ONCE REGENERATED GAC
	3-2	3-2	8	PHASE 3, RUN 2. GAC SYSTEM CONTAINS TWICE REGENERATED GAC
	3-3	3-3	9	PHASE 3, RUN 3. GAC SYSTEM CONTAINS THREE-TIMES REGENERATED GAC
	3-4	3-4	10	PHASE 3, RUN 4. GAC SYSTEM CONTAINS FOUR-TIMES REGENERATED GAC
	3-5	3-5	11	PHASE 3, RUN 5. GAC SYSTEM CONTAINS FIVE-TIMES REGENERATED GAC
F(9)	DATE	DTE		DATE OF SAMPLE